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

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

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

By DAVID R. LAGESON[1], EDWIN K. MAUGHAN, and WILLIAM J. SANDO

ABSTRACT

Lower Carboniferous strata of Wyoming (Mississippian to early Middle Pennsylvanian) represent two marine depositional sequences separated by a period of epeirogenic uplift and erosion. The Mississippian part of the succession is a wedge that thickens northwestward from a zero edge in southeastern Wyoming; this wedge is disconformably overlain by predominantly thin-bedded terrigenous strata of the upper part of the succession.

In western Wyoming, the lower depositional sequence is represented by the Madison Group, which includes the Mission Canyon and Lodgepole Limestones. The Lodgepole includes, in ascending order, a basal dark shale (Kinderhookian), which represents the upper tongue of the Cottonwood Canyon Member; the Paine Member (Kinderhookian); and the Woodhurst Member (early Osagean). The overlying Mission Canyon Limestone is of middle Osagean to early Meramecian age. Throughout most of central Wyoming, the lower depositional sequence is represented by the Madison Limestone, which includes six members, ranging from Kinderhookian to early Meramecian. These are, in ascending order, the Cottonwood Canyon Member (conodont-bearing shale, siltstone, and silty dolomite), lower dolomite member (thick-bedded crinoidal dolomite), Woodhurst Member (cross-bedded crinoidal dolomite and limestone), cherty dolomite member (thin-bedded dolomite and dolomitic limestone), cliffy limestone member (cherty bioclastic crinoidal limestone), and the Bull Ridge Member (a lower red and yellow shale and siltstone and an upper stromatolitic limestone and dolomite). In the Hartville uplift area of eastern Wyoming, the lower depositional sequence is represented by the Guernsey Formation, which consists of limestone and dolomitic limestone unconformably lying on Precambrian, Cambrian, and Ordovician rocks. Strata equivalent to the Madison Limestone in the Black Hills include the lower Mississippian Englewood Formation (red and purple dolomite, limestone, and shale) and the Kinderhookian-to-Osagean Pahasapa Limestone.

The upper depositional sequence of lower Carboniferous strata in Wyoming consists of three (four in western Wyoming) transgressive facies, which are members of the Amsden Formation. The Darwin Sandstone Member (late Meramecian to late Chesterian), the basal transgressive unit, rests disconformably on the Bull Ridge Member of the Madison. The Horseshoe Shale Member conformably overlies the Darwin and consists of a late Chesterian to Early Pennsylvanian succession of transgressive red beds. The Moffat Trail Limestone of western Wyoming is a transgressive wedge-shaped body of bioclastic limestone between the Horseshoe Shale and Ranchester Limestone Members of the Amsden Formation. In an alternative to the view expressed sequence is the Ranchester Limestone (late Chesterian-to-Morrowan in western Wyoming and Morrowan-to-Atokan in central Wyoming), which consists of interbedded dolomite, limestone, sandstone, and shale.

Two points of view are presented concerning the stratigraphic relations and paleontologic interpretation of the Amsden Formation. In an alternative to the view expressed above, the Pennsylvanian rocks in Wyoming comprise two stratigraphic sequences bounded by regional unconformities. Red mudstone and limestone characterize strata in the lower sequence, and sandstone and dolomite characterize strata in the upper sequence. Initial deposits of the lower sequence are red mudstone probably no older than about middle Morrowan, except in the subsurface of southwestern Wyoming, where early Morrowan strata may be present. The basal red mudstone lies unconformably upon Mississippian strata, except in the vicinity of the ancestral Rocky Mountain Front Range, where it lies upon Precambrian rocks. The red beds grade upward to interbedded limestone and mudstone of late Morrowan and early Atokan age, but the limestone strata are absent at many places because of beveling on a Middle Pennsylvanian erosional surface.

Initial deposits of the upper sequence are heterogeneous and locally may be thinly bedded red, green, or varicolored mudstone, sandstone, or dolomite of late Atokan to early Des Moinesian age. Basal strata of the upper sequence lie unconformably upon lower Pennsylvanian strata at most places in Wyoming; however, locally, where the lower Pennsylvanian strata are absent because of erosion or possibly because of nondeposition, the upper sequence lies upon Mississippian rocks. The upper sequence in central and northwestern Wyoming is mostly sandstone no younger than Des Moinesian. The upper sequence in eastern Wyoming consists of sandstone and dolomite about equally and also includes Upper Pennsylvanian strata as young as Virgilian. Upper Pennsylvanian strata are also part of the upper sequence in the thrust belt in western Wyoming. Pennsylvanian strata terminate upward at an erosional unconformity beneath Permian rocks everywhere in Wyoming.

The principal economic products from Carboniferous rocks in Wyoming are petroleum and high-calcium industrial limestone. Other commodities of minor importance include building stone and aggregate.

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INTRODUCTION

By David R. Lageson

Carboniferous strata in Wyoming (Mississippian and Pennslyvanian) include the Madison, Amsden, and Tensleep Formations and their equivalent units. This report is divided into two main parts dealing with stratigraphy and a third shorter part on economic products. The first part on stratigraphy deals with strata equivalent to and including the Mississippian Madison Limestone; the other discusses the Pennsylvanian Tensleep Formation and equivalent strata. Two points of view are presented concerning the stratigraphy and age relations of the Amsden Formation .We hope that this two-part discussion of stratigraphy will clearly define the age and stratigraphic relationships of the units involved.

The Madison Limestone thickens towards western Wyoming, where it attains group status and includes the Lodgepole and Mission Canyon Limestones. Throughout central Wyoming, the Madison has been divided into six members; these are, in ascending order, the Cottonwood Canyon Member, lower dolomite member, Woodhurst Member, cherty dolomite member, cliffy limestone member, and Bull Ridge Member. In the Hartville uplift area and the Black Hills of eastern Wyoming and western South Dakota, the Madison is represented by the Guernsey, Englewood, and Pahasapa Formations. The Amsden and Tensleep Formations of central Wyoming (Bighorn Mountains westward to the Gros Ventre and Teton Ranges) grade eastward into the Minnelusa, Hartville, Casper, and Fountain Formations, and southward into the Round Valley Limestone, Morgan Formation, and Weber Sandstone. Pennsylvanian rocks in the thrust belt of western Wyoming are included in the Wells Formation.

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 Geological Survey of Wyoming.

Carboniferous strata are typically exposed along the flanks of large asymmetric Precambrian-cored anticlines that formed during the Laramide orogeny (early Tertiary). These strata have been exposed as a result of late Tertiary regional uplift, erosion, and exhumation of Laramide structures. In western Wyoming, allochthonous strata are exposed on the hanging walls of west-dipping thrust plates of the Salt River, Snake River, Wyoming, and Hoback Ranges.

Carboniferous strata in Wyoming were first recognized by geologists of the U.S. Geological and Geographical Survey of the Territories during the 1860's and 1870's. Formal naming and recognition was done subsequently by the U.S. Geological Survey (Darton, 1904; Peale, 1893). The Geological Survey of Wyoming, since its inception in 1933, has published (most notably, Thomas and others, 1953) on various aspects of Wyoming's Carboniferous rocks. In recent years, increased petroleum production in the Rocky Mountains from Carboniferous reservoirs has maintained industry and academic interest in these strata.

ACKNOWLEDGMENTS

The Geological Survey of Wyoming gratefully acknowledges William J. Sando and Edwin K. Maughan for their contributions to this report. J. D. Love provided helpful suggestions during the compilation of the report.

LOWER PART OF THE CARBONIFEROUS

By William J. Sando

INTRODUCTION

The lower part of the Carboniferous (Mississippian and lower part of the Pennsylvanian) in Wyoming consists of a marine sequence of predominantly carbonate rocks, which attains a maximum thickness of approximately 660 m. These rocks crop out on the flanks of most of the mountain uplifts of the State and are present in the subsurface of the intermontane basins (fig. 1). Throughout most of Wyoming, the original geographic positions of the Carboniferous rocks were not appreciably affected by subsequent tectonic movements, but in the western part of the State (Salt River Range, Snake River Range, Wyoming Range, Hoback Range), Laramide overthrusting brought rocks deposited farther west into juxtaposition with an autochthonous sequence.

The rock sequence is represented by 12 different formations or parts of formations in different parts of the State (fig. 2). In a large area that occupies most of the central part of Wyoming, beds of Late Devonian, Early Mississippian, and early Late Mississippian (late Famennian-early Viséan) age are included in the Madison Limestone, which is overlain by the Amsden Formation of Late Mississippian to early Middle Pennsylvanian (late Viséan–early Westphalian) age. In the westernmost part of the State, the Madison is used as a group term that

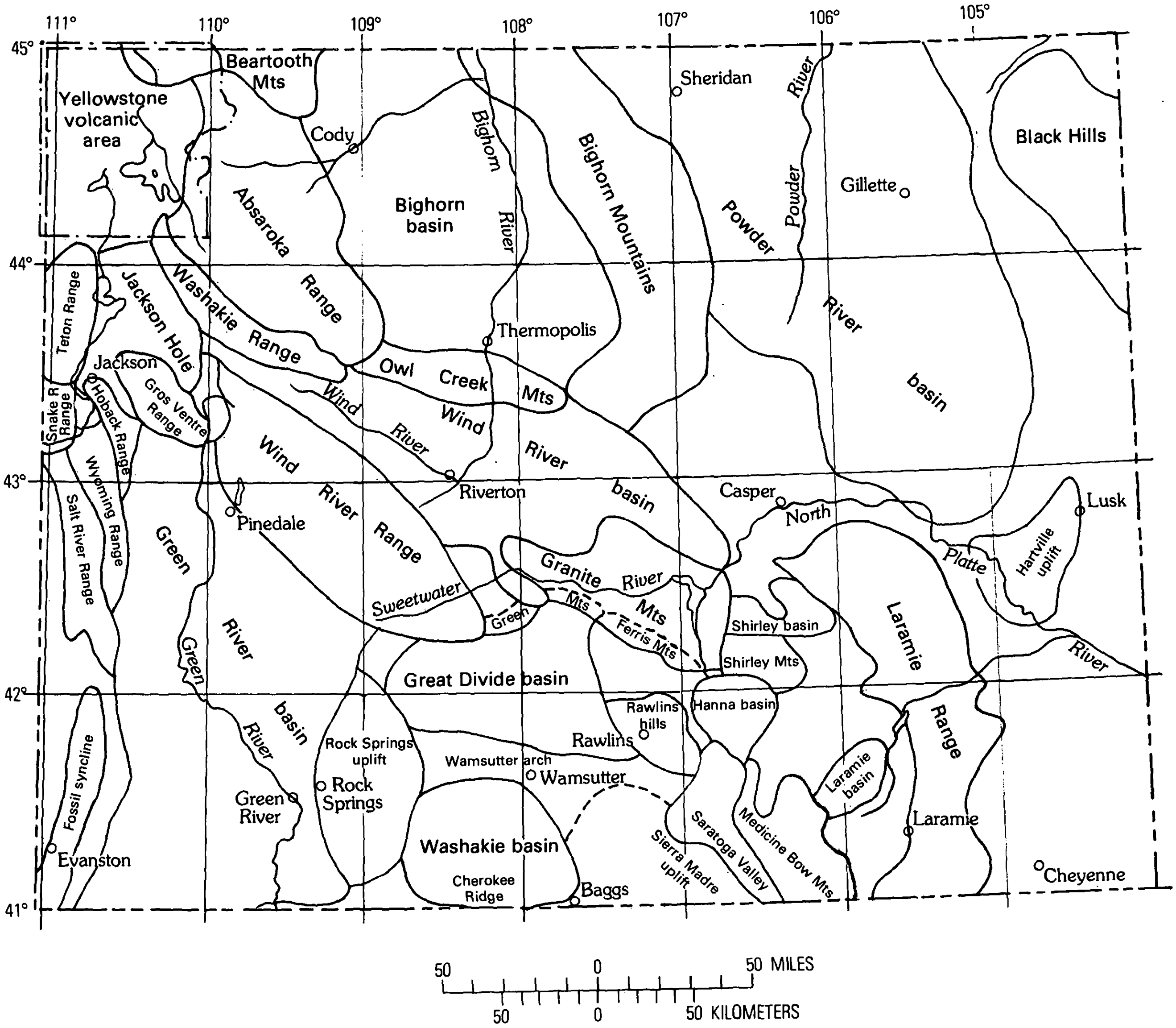


FIGURE 1.—Map of Wyoming showing present structural features (from Welder and McGreevy, 1966). Unnamed areas cannot be classified as either major uplifts or as basins.

includes two formations, the Lodgepole Limestone and Mission Canyon Limestone; the group is overlain by the Amsden Formation. In most of southeastern Wyoming, the lower part of the sequence consists of an unnamed sandstone unit of probable Late Devonian and Early Mississippian age overlain by the Madison Limestone (Early and early Late Mississippian), which is in turn overlain by the Casper Formation (Pennsylvanian and Permian) or the Fountain Formation (Pennsylvanian). In the Hartville uplift and adjacent basinal areas, the lower part of the sequence is the Guernsey Formation (Late Devonian and Early Mississippian), which is overlain by the Hartville Formation (Pennsylvanian and Permian). Terminology is variable in the subsurface of the Powder River basin in northeast Wyoming, but the Mississippian part of the sequence is most commonly called Madison Limestone and the Pennsylvanian part, Minnelusa Formation. In the northeastern corner of the State, on the flank of the Black Hills uplift, the Englewood Formation (Late Devonian and Early Mississippian) is overlain by the Pahasapa Limestone (Early Mississippian), which is in turn overlain by the Minnelusa Formation (Pennsylvanian and Permian). Nomenclature is uncertain because of the scarcity of information where the Carboniferous rocks are deeply buried in south-

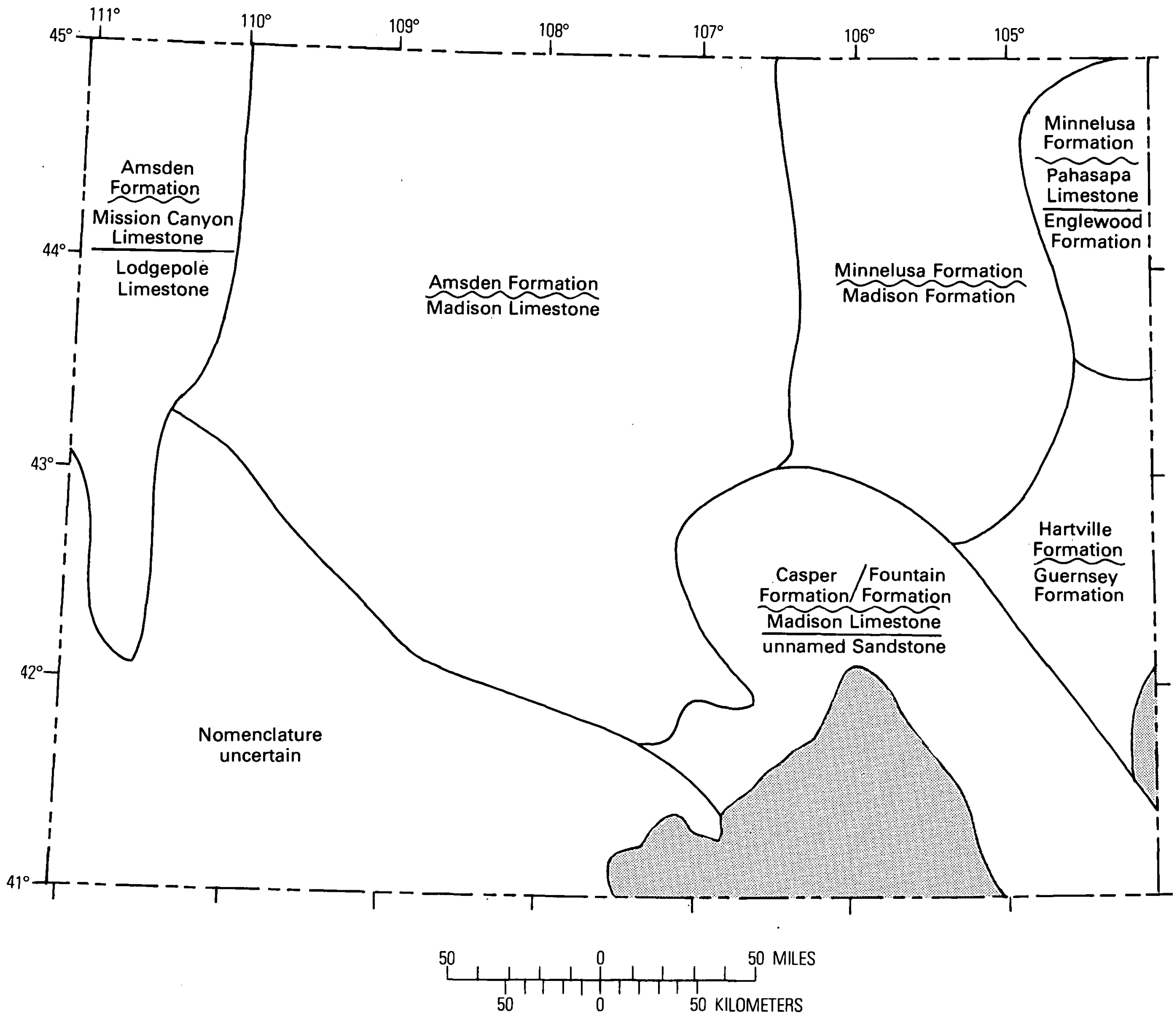


FIGURE 2.—Map of Wyoming showing formational nomenclature of Mississippian rocks and lower part of Pennsylvanian rocks. Mississippian rocks absent in shaded areas. Wavy line between formation names denotes disconformity; straight line indicates conformal contact. Precambrian rocks of the transcontinental arch shaded.

western Wyoming, which includes the Green River basin, Rock Springs uplift, and Washakie basin. Boundaries between areas of different nomenclature (fig. 2) are largely artificial and reflect different historical centers of classification of rocks of similar age and lithology.

This discussion is based mainly on regional syntheses by Mallory (1967), Sandberg and Mapel (1967), Sando (1976a), and Sando and others (1969, 1975). Other important regional summaries of the stratigraphy are Agatston (1954), Andrichuk (1955), Craig (1972), Mallory (1972), Rose (1976), Sandberg (1967), Sandberg and Klapper (1967), and Sando (1967b). Important studies of smaller areas in Wyoming are Bates (1955), Jenkins and McCoy (1958), Love and others (1953), Maughan (1963), McCaleb and Wayhan (1969), Sando (1967a, 1968, 1972, 1974, 1975, 1976b, 1977), Sando and Mamet (1974), and Todd (1964).

ACKNOWLEDGMENTS

I am deeply indebted to B. L. Mamet for foraminifer zone determinations, many of which are as yet unpublished. C. A. Sandberg kindly determined conodont zones in many sections and contributed stratigraphic data on the lower part of the Madison.

C. A. Sandberg and J. T. Dutro, Jr., reviewed the paper and provided useful suggestions.

REGIONAL STRATIGRAPHY

The Mississippian-early Middle Pennsylvanian succession in Wyoming represents two principal cycles of marine deposition separated by a period of epeirogenic uplift and erosion (fig. 3). The lower depositional sequence or cycle consists of the Madison Limestone and its correlatives; the upper depositional sequence or cycle consists of the Amsden Formation and its correlatives. Throughout most of Wyoming, the Mississippian-Pennsylvanian boundary is within the upper depositional sequence; sedimentation was continuous across the systemic boundary except in the eastern part of the State, where beds of Early to Middle Pennsylvanian age rest on beds of Early to Late Mississippian age.

The lower depositional cycle began in the Late Devonian, was interrupted briefly at the Devonian-Mississippian boundary, and continued into the Late Mississippian (early Meramecian). The upper depositional cycle began in the Late Mississippian (middle Meramecian) and continued into the Middle Pennsylvanian (Atokan). In terms of western European chronostratigraphy, the lower depositional sequence is Late Famennian-early Viséan, and the upper depositional sequence is late Viséan-early Westphalian. Deposition was continuous across the lower Carboniferous-upper Carboniferous boundary in most of the State. The major regional break in deposition began in the middle Viséan and extended into the Namurian.

An isopach map of the Mississippian part of the succession (fig. 4) shows a general thickening of these rocks northward and westward from a zero edge in southeastern Wyoming. Two cross sections parallel to thickness trends (fig. 5; see also table 1) show northward- and westward-expanding wedges of predominantly shelf carbonate rocks of the lower depositional sequence overlain disconformably by thin predominantly terrigenous rocks of the upper depositional sequence.

The character of the lower depositional sequence changes rapidly in adjacent southeastern Idaho, where terrigenous rocks were deposited in a deep basin west of the carbonate shelf margin. The Mississippian part of the upper depositional sequence thickens rapidly in western Wyoming, where a wedge of carbonate rocks extends eastward from a thick body of Upper Mississippian shelf carbonate rocks in Idaho. The Pennsylvanian (Morrowan and Atokan) part of the upper depositional sequence (not shown on fig. 5) is a nearly tabular body of shaley and sandy carbonate rocks throughout most of the State.

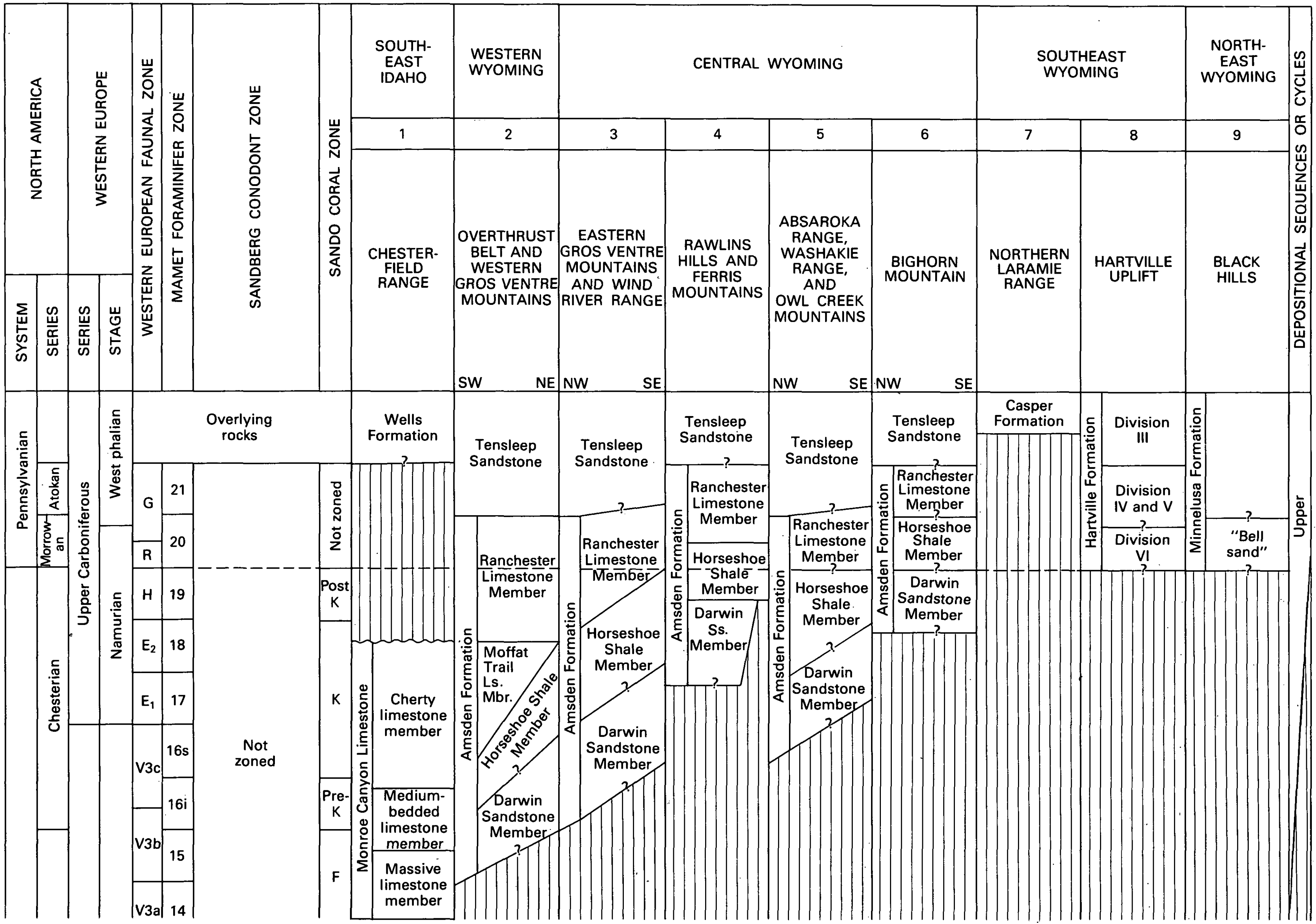
LOWER DEPOSITIONAL SEQUENCE

MADISON GROUP

In western Wyoming, the Madison is a group that includes the Lodgepole Limestone and the overlying Mission Canyon Limestone, formations whose type localities are in Montana. The Madison is about 375 m thick in this area. In parts of western Wyoming, conodont-bearing dark shale as much as 18 m thick is at the base of the Lodgepole Limestone, which rests disconformably on the Devonian Darby Formation. The dark shale represents the upper tongue of the Cottonwood Canyon Member of the Lodgepole, a unit of earliest Kinderhookian (early Tournaisian) age (fig. 3, column 2). The member contains conodonts of the *Siphonodella sandbergi* Zone (Sandberg and Mapel, 1967).

The Cottonwood Canyon Member is succeeded conformably by the Paine Member of the Lodgepole Limestone, which is at the base of the formation where the Cottonwood Canyon Member is absent. The Paine is about 50 m thick. The lower 3–5 m of the member consists of silty, glauconitic, crinoidal limestone and is overlain by cherty thin-bedded silty fine-grained limestone. The lower crinoidal part of the Paine contains rare corals and brachiopods of Coral Zone A of Sando and others (1969) and conodonts of the Lower *Siphonodella crenulata* Zone (Sandberg and Mapel, 1967). The poorly fossiliferous remainder of the Paine Member contains corals and brachiopods of Coral Zone B, foraminifers of Zone pre-7 (Mamet, *in* Sando and others, 1969), and conodonts of the *Siphonodella isosticha*-Upper *S. crenulata* Zone of Sandberg (written commun., 1977). The Paine Member is of Kinderhookian (middle Tournaisian) age.

The Paine Member is overlain conformably by the Woodhurst Member of the Lodgepole Limestone, which consists of about 80 m of cyclically interbedded, thin-bedded silty fine-grained limestone and oolitic crinoidal limestone. This unit contains a rich fauna of conodonts, foraminifers, brachiopods, corals, bryozoans, and gastropods which represent the *Siphonodella isosticha*-Upper *S. crenulata* Zone, the *Gnathodus typicus* Zone, the *Pseudopolygnathus* n. sp. Zone, foraminiferal Zones 7 and 8, and Coral Zone C_1. The Woodhurst Member includes beds of late Kinderhookian (middle Tournaisian) and early Osagean (middle and upper Tournaisian) age.



NORTH AMERICA
WESTERN EUROPE
SYSTEM
SERIES
SERIES
STAGE
WESTERN EUROPEAN FAUNAL ZONE
MAMET FORAMINIFER ZONE
SANDBERG CONODONT ZONE
SANDO CORAL ZONE
SOUTH-EAST IDAHO
WESTERN WYOMING
CENTRAL WYOMING
SOUTHEAST WYOMING
NORTH-EAST WYOMING
DEPOSITIONAL SEQUENCES OR CYCLES
1
2
3
4
5
6
7
8
9
CHESTER-FIELD RANGE
OVERTHRUST BELT AND WESTERN GROS VENTRE MOUNTAINS
EASTERN GROS VENTRE MOUNTAINS AND WIND RIVER RANGE
RAWLINS HILLS AND FERRIS MOUNTAINS
ABSAROKA RANGE, WASHAKIE RANGE, AND OWL CREEK MOUNTAINS
BIGHORN MOUNTAIN
NORTHERN LARAMIE RANGE
HARTVILLE UPLIFT
BLACK HILLS
SW
NE
NW
SE
NW
SE
NW
SE
Pennsylvanian
Atokan
Morrowan
Chesterian
Upper Carboniferous
West phalian
Namurian
G
R
H
E2
E1
V3c
V3b
V3a
21
20
19
18
17
16s
16i
15
14
Overlying rocks
Not zoned
Not zoned
Post K
K
Pre-K
F
Wells Formation
Monroe Canyon Limestone
Cherty limestone member
Medium-bedded limestone member
Massive limestone member
Tensleep Sandstone
Amsden Formation
Ranchester Limestone Member
Moffat Trail Ls. Mbr.
Horseshoe Shale Member
Darwin Sandstone Member
Horseshoe Shale Member
Darwin Ss. Member
Casper Formation
Hartville Formation
Division III
Division IV and V
Division VI
Minnelusa Formation
"Bell sand"
Upper
?

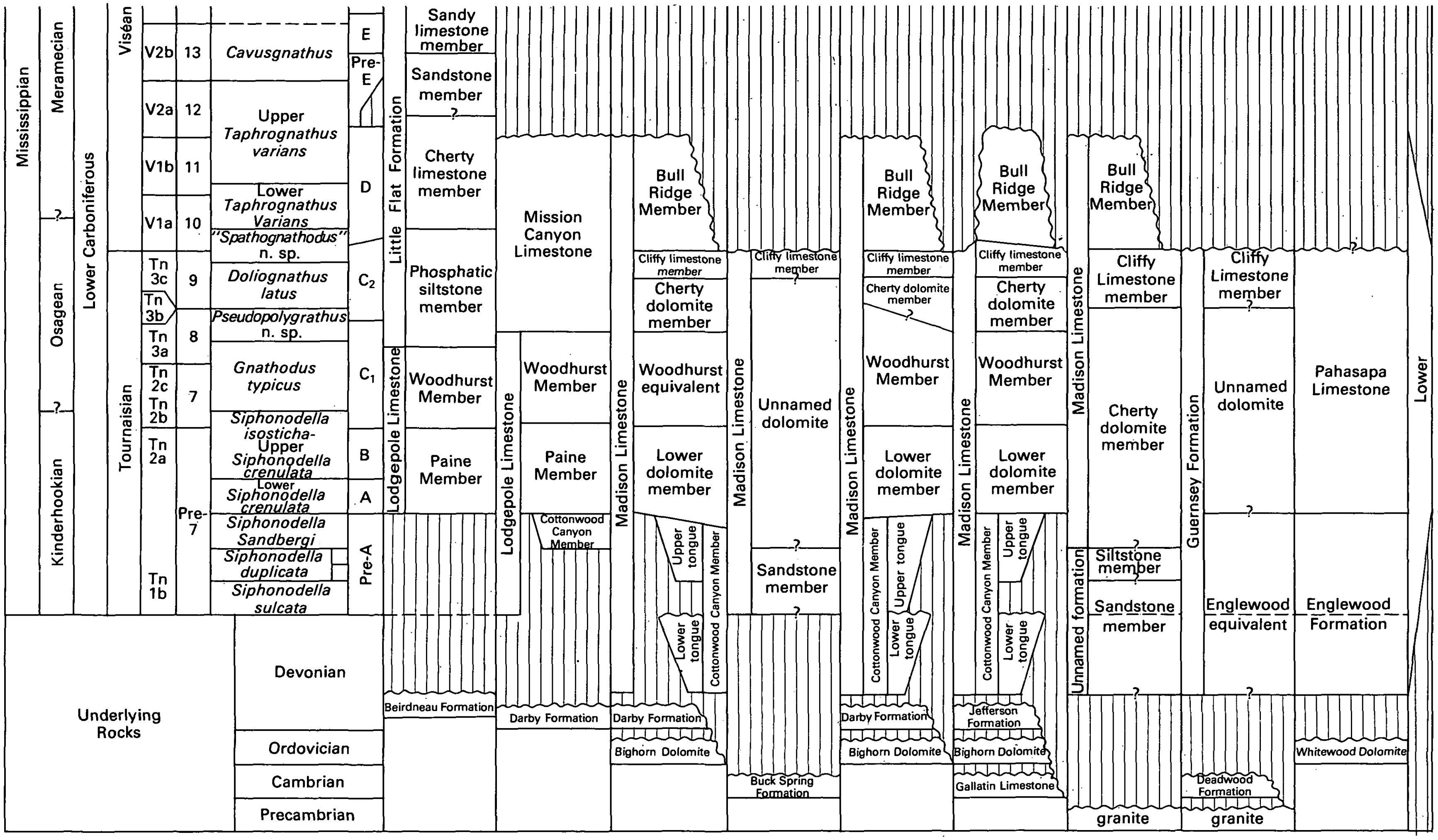


FIGURE 3.—Nomenclature and temporal relations of Mississippian rocks and lower part of Pennsylvanian rocks in Wyoming and adjacent parts of Idaho. [Vertical lines denote hiatus. Sources of data for stratigraphic columns (indicated by numbers) modified from: 1, Dutro and Sando (1963), Sando and others (1976), Poole and Sandberg (1977); 2, Sandberg and Mapel (1967), Sando and others (1975), Sando (1977); 3, Sandberg and Mapel (1967), Sandberg and Klapper (1967), Sando (1967a, 1977), Sando and others (1975); 4, Sando (1967), Sando and others (1975), M. W. Reynolds (written commun., 1968); 5, Sando (1967a, 1975), Sando and others (1975), Sandberg and Mapel (1967), Sandberg and Klapper (1967), Sandberg (1967); 6, Sando (1976b), Sando and others (1975), Sandberg (1967), Sandberg and Klapper (1967), Sandberg and Mapel (1976); 7, Maughan (1963), Mallory (1967), Sando and Sandberg (unpub. data, 1977); 8, Love and others (1953), Sando (unpub. data, 1977); 9, Sandberg and Mapel (1967), Sando (unpub. data, 1977). Foraminifer and coral zones modified slightly from Sando and others (1969). Conodont zones from Sandberg and Mapel (1967) and Sandberg (written commun., 1977).]

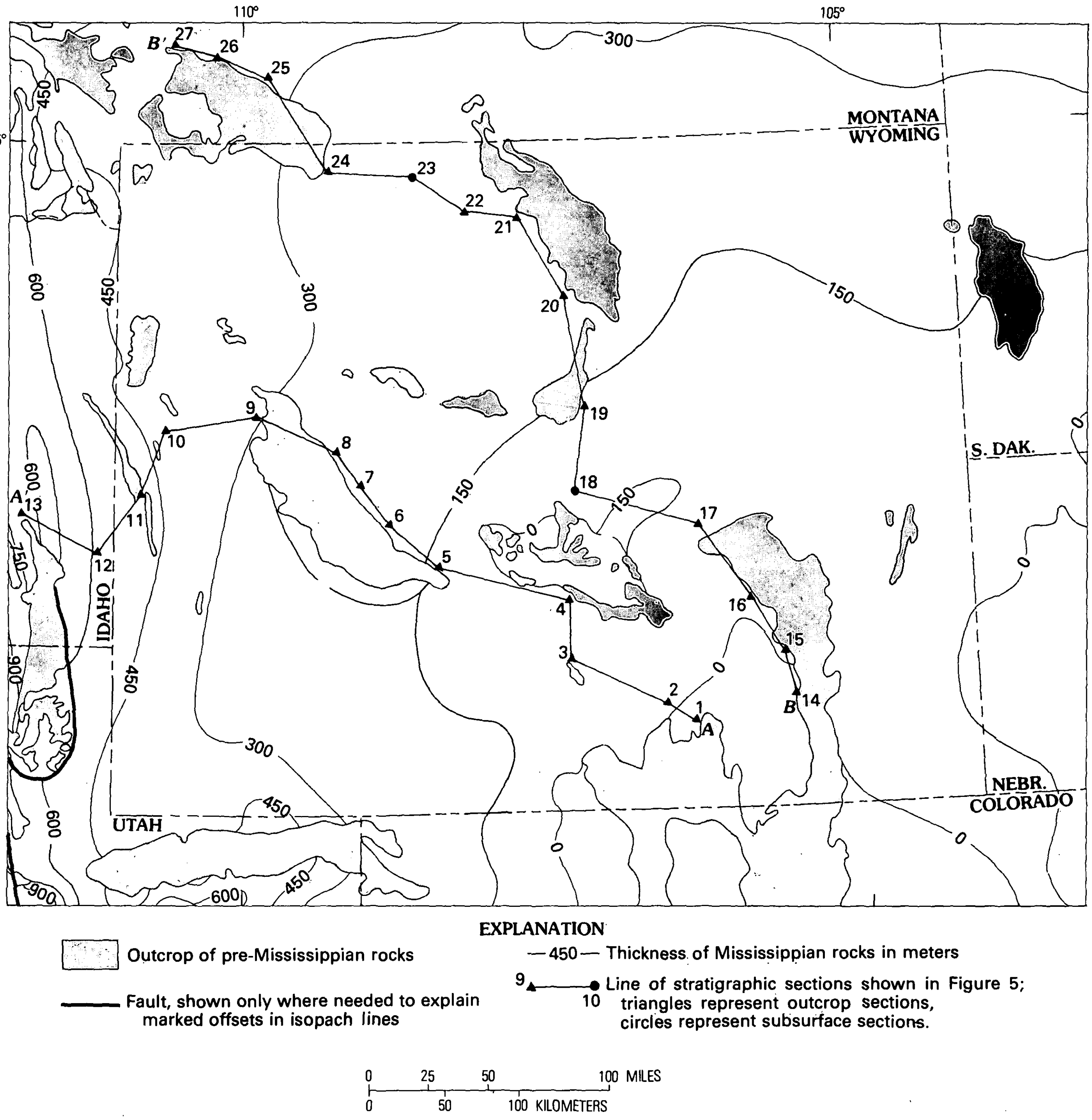


FIGURE 4.—Thickness of Mississippian rocks in Wyoming and adjacent areas, trends of cross sections, and locations of key stratigraphic sections (numbered) shown in figure 5 (modified from Sando, 1976a).

The Woodhurst Member of the Lodgepole Limestone is succeeded conformably by the Mission Canyon Limestone, which consists of interbedded, thick-bedded crinoidal oolitic limestone and cherty thin-bedded fine-grained dolomite and dolomitic limestone in the lower half and dolomite and dolomitic limestone interbedded with cherty predominantly fine-grained limestone in the upper half. The upper half is also characterized by two solution-breccia zones except in the Hoback Range, where three evaporitic zones are preserved (Sando, 1977). The total thickness of the Mission Canyon in western Wyoming is about 250 m. The formation is moderately fossiliferous, containing foraminifers,

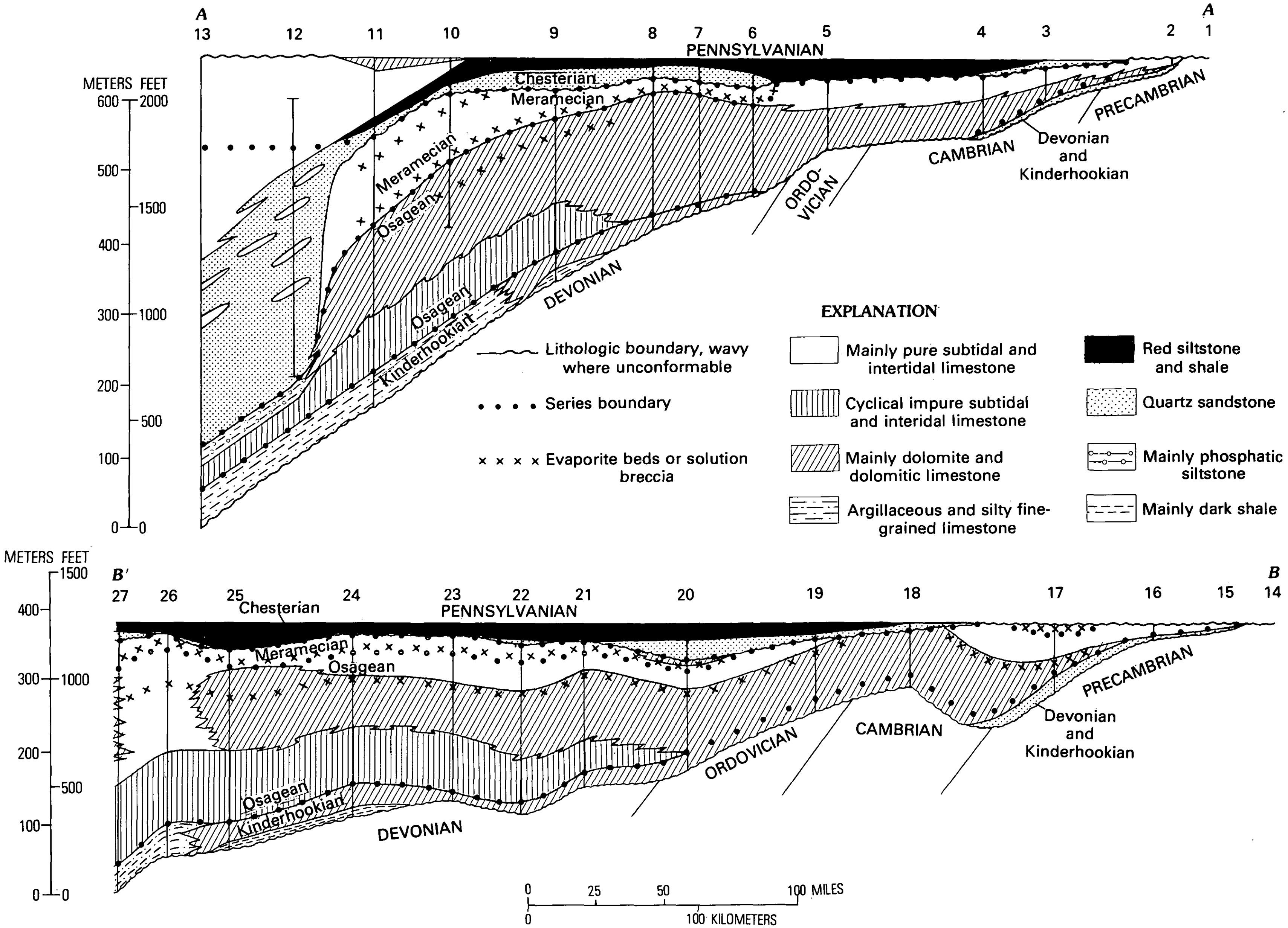


FIGURE 5.—Stratigraphic and structural relations of Mississippian rocks from southeastern Wyoming to southeastern Idaho (A–A') and from southeastern Wyoming to southern Montana (B–B'). Modified from Sando (1976a). Locations of stratigraphic sections are shown on figure 4 and described in table 1.

TABLE 1.—*Geographic locations and sources of information for stratigraphic sections shown on figures 4 and 5*

[Locality numbers refer to numbers shown on figs. 4 and 5]

Section No.	Locality name	Geographic location	Source of information
1	Arlington	Approximately T. 18 N., R. 79 W., Carbon County, Wyo.	Maughan (1963)
2	Elk Mountain	Approximately T. 19 N., R. 82 W., Carbon County, Wyo.	Do.
3	Buck Spring	Sec. 33, T. 23 N., R. 88 W., Carbon County, Wyo.	Sando (1967a); Sando and others (1975)
4	Cottonwood Creek	Secs. 27 and 34, T. 27 N., R. 88 W., Carbon County, Wyo.	Reynolds, M. W. (written commun., 1968)
5	Sweetwater Canyon	Secs. 27 and 34, T. 29 N., R. 97 W., Fremont County, Wyo.	Sando (1967a), Sando and others (1975)
6	Sinks Canyon	Sec. 18, T. 32 N., R. 100 W., Fremont County, Wyo.	Do.
7	Washakie Reservoir	Sec. 18, T. 1 S., R. 2 W., Fremont County, Wyo	Do.
8	Bull Lake Creek	Secs. 2 and 3, T. 2 N., R. 4 W., Fremont County, Wyo.	Do.
9	Big Sheep Mountain	Sec. 6, T. 38 N., R. 108 W., and sec. 31, T. 39 N., R. 108 W., Sublette County, Wyo.	Blackwelder, Eliot (unpub. data); Richmond (1945)
10	Hoback Canyon	Sec. 3, T. 38 N., R. 115 W., Teton County, Wyo	Sando (1977); Sando and others (1975)
11	Haystack Peak	Sec. 19, T. 34 N., R. 117 W., Lincoln County, Wyo.	Do.
12	Wells Canyon	Secs. 10 and 11, T. 10 S., R. 45 E., Caribou County, Idaho	Gulbrandsen and others (1956)
13	Little Flat Canyon	Secs. 17 and 20, T. 7 S., R. 40 E., Bannock County, Idaho	Dutro and Sando (1963), Sando (1977), Sando and others (1976)
14	Laramie Range	Approximately T. 20 N., R. 72 W., Albany County, Wyo.	Maughan (1963)
15	Wheatland Reservoir	Sec. 17, T. 23 N., R. 73 W., Albany County, Wyo.	Do.
16	Marshall	Approximately T. 26 N., and T. 27 N., R. 75 W., Albany County, Wyo.	Do.
17	Casper Mountain	Sec. 9, T. 32 N., R. 79 W., Natrona County, Wyo.	Do.
18	National Co-op Refining Co., Wallace Creek No. 2 well.	Sec. 16, T. 34 N., R. 87 W., Natrona County, Wyo.	American Stratigraphic Co.
19	Middle Buffalo Creek	Secs. 20 and 21, T. 40 N., R. 86 W., Natrona County, Wyo.	Sando (1976b), Sando and others (1975)
20	Tensleep Canyon	Sec. 27, T. 48 N., R. 87 W., Washakie County, Wyo.	Sando (unpub. data, 1977), Sando and others (1975)
21	Shell Canyon	Secs. 9 and 17, T. 53 N., R. 90 W., Big Horn County, Wyo.	Do.
22	Sheep Mountain	Sec. 35, T. 54 N., R. 94 W., and sec. 2, T. 53 N., R. 94 W., Big Horn County, Wyo.	Do.
23	Ohio Oil Co., Easton unit 6 well	Sec. 28, T. 56 N., R. 97 W., Big Horn County, Wyo.	American Stratigraphic Co.
24	Clarks Fork Canyon	Secs. 5, 6, and 7, T. 56 N., R. 103 W., Park County, Wyo.	Sando (1972, 1975), Sando and others (1975)
25	Ben Bow Mine Road	Secs. 20 and 29, T. 5 S., R. 16 E., Stillwater County, Mont.	Sando (1972)
26	Baker Mountain	Secs. 34 and 35, T. 3 S., R. 12 E., Sweetgrass and Park Counties, Mont.	Do.
27	Livingston	Secs. 1 and 2, T. 3 S., R. 9 E., and sec. 35, T. 2 S., R. 9 E., Park County, Mont.	Do.

corals, brachiopods, gastropods, and bryozoans and rare conodonts. Foraminiferal Zones 8 through 11 and Coral Zones C_1, C_2 and D are represented in the sequence. The Mission Canyon ranges in age from middle Osagean into early Meramecian (late Tournaisian-early Viséan).

MADISON LIMESTONE

Throughout most of Wyoming, the lower depositional sequence or cycle is represented by a single formation, the Madison Limestone. Six members are recognized in the Madison in most of central Wyoming, but in the Rawlins hills and in southeastern Wyoming, the lower four members are not recognizable, and sandstone occurs at the base of the Mississippian (fig. 3). Although the members of the Madison were based on outcrop studies, examination of well logs from the Bighorn, Wind River, and Powder River basins indicate that most of the members are also recognizable in the subsurface. The

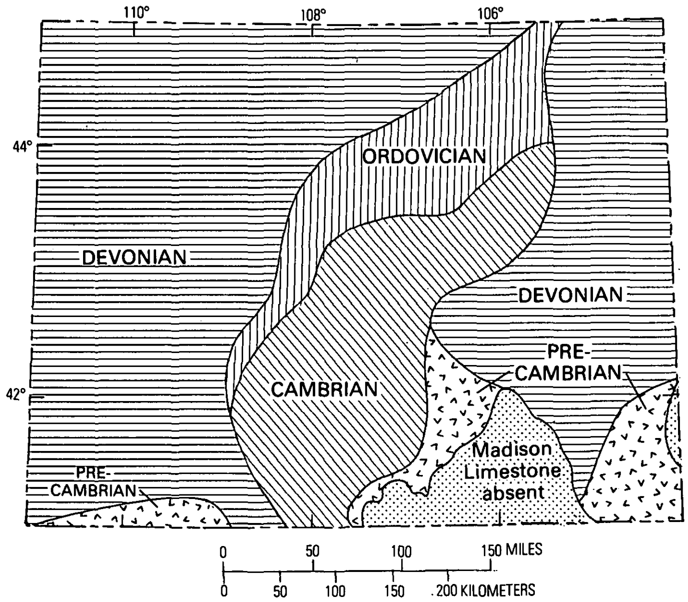


FIGURE 6.—Paleogeologic map showing ages of rocks underlying the Madison Limestone and equivalent rocks in Wyoming. Modified from Craig (1972, fig. 2) and Baars (1972, figs. 6 and 8).

Madison Limestone rests unconformably on a variety of formations ranging from Precambrian to Devonian in age; the subcrop becomes progressively younger northward and westward from the zero edge of the Madison in southeastern Wyoming (fig. 6).

Throughout most of central Wyoming, the basal unit of the Madison Limestone is the Cottonwood Canyon Member, which consists mostly of conodont-bearing shale, siltstone, and silty dolomite as much as 12 m thick. The member includes a lower tongue of latest Devonian (Famennian) age separated by a disconformity from an upper tongue of early Kinderhookian age (*Siphonodella sulcata, S. duplicata,* and *S. sandbergi* conodont zones).

The Cottonwood Canyon Member is succeeded conformably by the lower dolomite member, which is mostly thick-bedded crinoidal dolomite and dolomitic limestone as much as 30 m thick. The member contains a sparse fauna of conodonts, corals, and brachiopods and is of Kinderhookian (middle Tournaisian) age. It is approximately equivalent to the Paine Member of the Lodgepole, and a lateral transition into the Paine can be observed in outcrop sections in the Beartooth Mountains of southern Montana (Sando, 1972). In the Owl Creek and southern Bighorn Mountains, the underlying Cottonwood Canyon Member is absent, and the lower dolomite member rests directly on beds of Cambrian, Ordovician, or Devonian age.

The lower dolomite member is overlain conformably by the Woodhurst Member or equivalent beds throughout most of central Wyoming. In the Abasaroka Range and central and northern Bighorn Mountains, the lower part of this member consists of crossbedded crinoidal dolomite or thick-bedded oolitic limestone, and the upper part consists of typical Woodhurst facies silty, thin-bedded, cyclically interbedded fine-grained limestone and bioclastic crinoidal limestone. The Woodhurst Member attains a maximum thickness of about 90 m. In the Wind River Mountains, Owl Creek Mountains, and southern Bighorn Mountains, the entire member is mostly crossbedded crinoidal dolomite and limestone. The typical Woodhurst facies is a wedge that pinches out southward from Montana and eastward from western Wyoming (fig. 5). The typical Woodhurst facies contains conodonts (rare) and foraminifers, brachiopods, and corals (moderately abundant). Foraminifer Zones 7 and 8 are represented throughout most of central Wyoming, and Zone 9 has been identified at the top of the member in the Absaroka Range. Coral Zone C_1 is also represented. The Woodhurst is mostly Osagean in age but contains some beds of Kinderhookian age in the lower part. The Kinderhookian-Osagean boundary is commonly placed at the base of the member for convenience. In terms of western European chronostratigraphy, the Woodhurst is middle and upper Tournaisian in age.

The Woodhurst Member is succeeded conformably by the cherty dolomite member, whose maximum thickness is about 70 m. The member consists of shattered and brecciated, thin-bedded, fine-grained cherty dolomite and dolomitic limestone at most localities, but elsewhere includes some beds of crinoidal or fine-grained limestone. The commonly shattered character of the beds suggests that the sequence was originally evaporitic in part and has subsequently been leached. Fossils are extremely rare, but a few brachiopods and corals of Osagean age have been found at some localities. The age of the cherty dolomite, bracketed by dated units above and below, is late Osagean (late Tournaisian) at most localities.

The cherty dolomite member is overlain conformably by the cliffy limestone member, which attains a maximum thickness of about 65 m. The upper part of the member consists of a very widespread sequence of commonly cherty, fine- to coarse-grained, mostly thick-bedded bioclastic crinoidal limestone and dolomite that contains abundant spiriferoid brachiopods and some corals and foraminifers. In central Wyoming, a solution breccia that represents a leached evaporite-carbonate-terrigenous sequence occurs at the base of the member, except in the southern Wind River Mountains and Rawlins hills. The beds above the solution breccia are brecciated as a result of collapse. Red sandstone and siltstone were deposited in solution cavities throughout the member during pre-Amsden uplift and Amsden deposition (Sando, 1974). The member contains the Zone 9 foraminifer fauna and corals of Zone C_2 at most localities, except in the northern Bighorn Mountains, where foraminifer Zone 10 has been found at a few places. The cliffy limestone member is of upper Osagean (upper Tournaisian and lowermost Viséan) age. For convenience, the Osagean-Meramecian boundary is commonly placed at the top of the member.

The cliffy limestone member is overlain conformably by the Bull Ridge Member in much of central Wyoming. The Bull Ridge Member reaches a maximum thickness of about 25 m and consists of a lower unit of red and yellow shale and siltstone and minor thin carbonate beds and an upper unit of thin- to medium-bedded, sparsely cherty, fine- to medium-grained, commonly stromatolitic limestone or dolomite. The lower unit is commonly a solution breccia, and the upper unit is commonly collapsed, indicating the former presence of evaporite beds. Sinkholes and solution cavities related to pre-Amsden emergence and filled by Amsden sediments are common in the Bull Ridge Member (Sando, 1974). The member was partly or entirely removed by pre-Amsden erosion at many localities in central Wyoming, particularly in the southern Wind River Mountains, eastern Owl Creek Mountains, and southern Bighorn Mountains. The upper part of the Bull Ridge Member contains corals and brachiopods of Zone D; foraminifers of Zones 10, 11, and (rarely) 12; and conodonts (rare) of the Upper or Lower *Taphrognathus varians* Zone.

In the Rawlins hills and Ferris Mountains, the Madison includes a lower, poorly dated sandstone member thought to be of Kinderhookian age, overlain by dolomite equivalent to the lower dolomite member, Woodhurst Member, and cherty dolomite member, and capped by the cliffy limestone member (fig. 3). In the northern Laramie Range, the Madison conformably overlies an unnamed quartz sandstone and siltstone sequence of probable Devonian and early Kinderhookian age, formerly regarded as the Cambrian and Ordovician Deadwood Formation. The Madison here consists of the cherty dolomite member, cliffy limestone member, and, locally, the Bull Ridge Member. Farther south in the Laramie Range, the carbonate appears to interfinger with quartz sandstone and conglomerate that unconformably overlies Precambrian granite (Maughan, 1963); exact age relationships remain to be determined in this area.

GUERNSEY FORMATION

In the Hartville uplift and adjacent subsurface, rocks equivalent to the Madison Limestone are included in the Guernsey Formation, which unconformably overlies quartzite of the Cambrian and Ordovician Deadwood Formation and Precambrian granite (Love and others, 1953). The lower part of the Guernsey consists of red siltstone of probable Devonian and Mississippian age regarded as an equivalent of the Englewood Formation of the Black Hills. Above the siltstone is unnamed dolomite and dolomitic limestone that is overlain by the cliffy limestone member. The Guernsey attains a maximum thickness of about 90 m.

ENGLEWOOD FORMATION AND PAHASAPA LIMESTONE

In the Black Hills and adjacent subsurface, the base of the Carboniferous is included in the Englewood Formation, a sequence of red to purple dolomite, dolomitic limestone, limestone, and shale as much as 27 m thick (Klapper and Furnish, 1962; Sandberg and Mapel, 1967). The Englewood is overlain by the Pahasapa Limestone, which includes limestone and dolomite of Kinderhookian and Osagean age as much as 190 m thick.

UPPER DEPOSITIONAL SEQUENCE

AMSDEN FORMATION

In western and central Wyoming, the upper depositional sequence or cycle is represented by the Amsden Formation (fig. 2), a transgressive sequence of quartz sandstone, siltstone, shale ,and carbonate rocks that attains a maximum thickness of about 150 m. The Amsden includes three members, except in western Wyoming, where four are recognized (fig. 3).

The age and correlation of the Amsden Formation have been the subjects of much controversy. The interpretations summarized herein are based on a comprehensive study of the physical stratigraphy and paleontology of the Amsden Formation in Wyoming by Sando and others (1975). The physical stratigraphy in this detailed analysis was based on study of 50 stratigraphic sections in Wyoming. The age and correlation of the Amsden was based on study of 160 collections including well over

6,000 specimens of fossils representing more than 350 taxa by a team of 10 paleontologists, each expert in one of the biologic groups represented. Critical age determinations rested mainly on study of foraminifers, algae, and brachiopods by specialists who worked independently and had no preconceptions about the physical stratigraphy when they interpreted the ages of fossil assemblages at various localities. In another part of this paper, E. K. Maughan presents a different interpretation of the Amsden, based mostly on physical stratigraphy, that emphasizes two presumed unconformities not recognized by Sando and others (1975). We have examined Maughan's reinterpretations of the paleontologic evidence and cannot agree with his conclusions.

The basal unit of the Amsden at most localities is the Darwin Sandstone Member, which consists of unfossiliferous, thin- to thick-bedded, ordinarily crossbedded, white to red, fine- to medium-grained quartz sandstone as much as 65 m thick. The Darwin rests disconformably on the Bull Ridge Member or the underlying cliffy limestone member of the Madison (Sando and others, 1975, pl. 1). At some localities, the Darwin is absent or present only in sinkholes in the Madison, and the basal unit is the Horseshoe Shale Member, which ordinarily overlies the Darwin. The Darwin Sandstone ranges in age from late Meramecian (late Viséan) in western Wyoming to late Chesterian (Namurian) in east-central Wyoming, on the basis of paleontologic dating of the overlying and underlying beds.

The Darwin is overlain conformably by a transgressive red-bed sequence named the Horseshoe Shale Member. This unit consists of a much as 45 m of red siltstone, shale, and rare thin beds of fine-grained sandstone and limestone. Although fossils are generally rare in the Horseshoe, occurrences of ostracodes, mollusks, brachiopods, foraminifers, and, to a limited extent, corals support a late Chesterian (early and middle Namurian) age in western and west-central Wyoming and a Morrowan (late Namurian-early Westphalian) age in the Bighorn Mountains and Rawlins hills. Foraminifer Zones 18, 19, and 20 are represented.

In western Wyoming, the Moffat Trail Limestone Member is a transgressive wedge-shaped body of carbonate rock as much as 33 m thick that intervenes between the Horseshoe Shale Member and the Overlying Ranchester Limestone Member of the Amsden. The Moffat Trail Member is predominantly fossiliferous, cherty, thin- to thick-bedded, medium- to coarse-grained crinoidal bioclastic limestone. The fauna consists of abundant foraminifers, bryozoans, brachiopods, ostracodes, gastropods, and corals that represent foraminifer Zones 17 and 18 and coral Zone K. The Moffat Trail is of Chesterian (late Viséan-early Namurian) age.

The highest unit in the Amsden is the Ranchester Limestone Member, which conformably overlies the Moffat Trail Limestone Member in western Wyoming and the Horseshoe Shale Member elsewhere. The Ranchester is a heterogeneous sequence of interbedded cherty dolomite and limestone, sandstone, and shale that attains a maximum thickness of about 75 m. The member contains a sparse normal marine fauna dominated by brachiopods and mollusks. The distribution of brachiopods and foraminifers indicates a late Chesterian-Morrowan age in western Wyoming and a Morrowan-Atokan age in central Wyoming.

CASPER FORMATION

The Casper Formation is a sequence of quartz sandstone and carbonate rocks in the Laramie basin and on the flanks of the Laramie Range in southeastern Wyoming. The Casper includes beds of Pennsylvanian and Permian age; the Pennsylvanian part ranges from about 30 to 180 m in thickness (Mallory, 1967). Equivalents of the Amsden Formation (Morrowan-Atokan) are present in parts of southeastern Wyoming, but Missourian and Des Moinesian rocks disconformably overly the Madison on the Pathfinder and Front Range uplifts (Mallory, 1963, 1967).

FOUNTAIN FORMATION

The Fountain Formation, named for exposures along the Front Range in Colorado, is a sequence of red sandstone, conglomerate, and arkose on the flanks of the Pennsylvanian uplifts in southeastern Wyoming. According to Mallory (1967), the Fountain ranges in age from Atokan to Virgilian. Hence, the Fountain may contain beds equivalent to the upper part of the Amsden Formation.

HARTVILLE FORMATION

The name Hartville Formation is applied to a sequence of sandstone, shale, and carbonate rocks of Pennsylvanian and Permian age in the Hartville uplift and adjacent subsurface in southeastern Wyoming. The six divisions of the formation are numbered from I at the top to VI at the base (Love and others, 1953).

Division VI, also known as the Fairbank Formation, is mostly unfossiliferous quartz sandstone that disconformably overlies the Guernsey Formation. The age of this unit is Chesterian and (or) Morrowan, probably the latter, which indicates that it is equivalent to the Darwin Sandstone Member of the Amsden Formation and, in fact, is probably laterally continuous with the Darwin. Division VI attains a maximum thickness of about 30 m. Thickness varies greatly depending on the topography of the karst surface on which it was deposited.

Division VI is conformably overlain by Division V, which consists principally of cherty limestone containing red shale beds. The overlying Division IV consists of red shale containing limestone and dolomite beds. Divisions IV and V are commonly lumped together for stratigraphic analysis to form a limestone-shale interval that attains a maximum thickness of about 90 m. Brachiopods, conodonts, foraminifers, corals, and bryozoans found near the base of Division V suggest a Morrowan age, and fusulinids from Division IV are of Atokan age. The combined Division IV–V unit is probably equivalent to and continuous with the Horseshoe Shale Member and Ranchester Limestone Member of the Amsden Formation.

Division IV is overlain conformably by Division III, a sequence of carbonate and quartz sandstone of Des Moinesian age that is equivalent to the lower part of the Tensleep Sandstone.

MINNELUSA FORMATION

The Minnelusa Formation, named for exposures in the Black Hills, is a sequence of carbonate, sandstone, and solution breccias or evaporite beds of Pennsylvanian and Permian age (Agatston, 1954; Bates, 1955; Mallory, 1967). The name has been used in northeastern Wyoming on the flank of the Black Hills and in the subsurface of the Powder River basin. The Minnelusa disconformably overlies the Pahasapa Limestone in the Black Hills and the Madison Limestone in the subsurface. A basal sandstone of probable Morrowan age, the Bell sand of subsurface usage, is probably laterally continuous with the Darwin Sandstone Member of the Amsden Formation. Beds equivalent to the Horseshoe and Ranchester Members of the Amsden are probably present in the sequence above the Bell sand.

SUMMARY OF GEOLOGIC HISTORY

During the early part of Carboniferous time, most of Wyoming was part of the Cordilleran platform, a broad cratonic area of relatively thin marine deposition that extended from southern Canada southward into Mexico (fig. 7). Extending across the southeast corner of the state was the Transcontinental arch, an emergent linear positive area that divided most of the United States into eastern and western areas of deposition and acted as a barrier to faunal migrations. Immediately west of Wyoming was the Cordilleran geosyncline, whose eastern part was a foreland basin during Mississippian time. West of the foreland basin, the geosyncline was divided into Antler orogenic highland, inner-arc basin, and island arc. The paleogeographic development described below has been illustrated by a series of maps in Sando (1976a).

Late Devonian regression created a land area of low relief in Wyoming. During latest Devonian (Famennian) and early Kinderhookian (early Tournaisian) times, a sea advanced rapidly onto the Cordilleran platform from southwest of Wyoming over a terrane composed of Precambrian, Cambrian, Ordovician, and Devonian rocks. Terrigenous and silty carbonate rocks (Cottonwood Canyon Member of Madison Limestone) were deposited in shallow marine basins on the Cordilleran platform, and the Transcontinental arch was a land area bordered on the west by an apron of quartz sand derived from the arch. Mild epeirogenic movements at the end of the Devonian caused temporary emergence or stillstand over most of the State.

Continued transgression during late Kinderhookian (early middle Tournaisian) time caused the sea to expand and cover all but the southeast corner of Wyoming. Subtidal and intertidal carbonate sediments (Madison Limestone) were deposited over most of the State except for deeper water carbonate rocks (Paine Member of Lodgepole Limestone) deposited on the eastern slope of the foreland basin in western Wyoming.

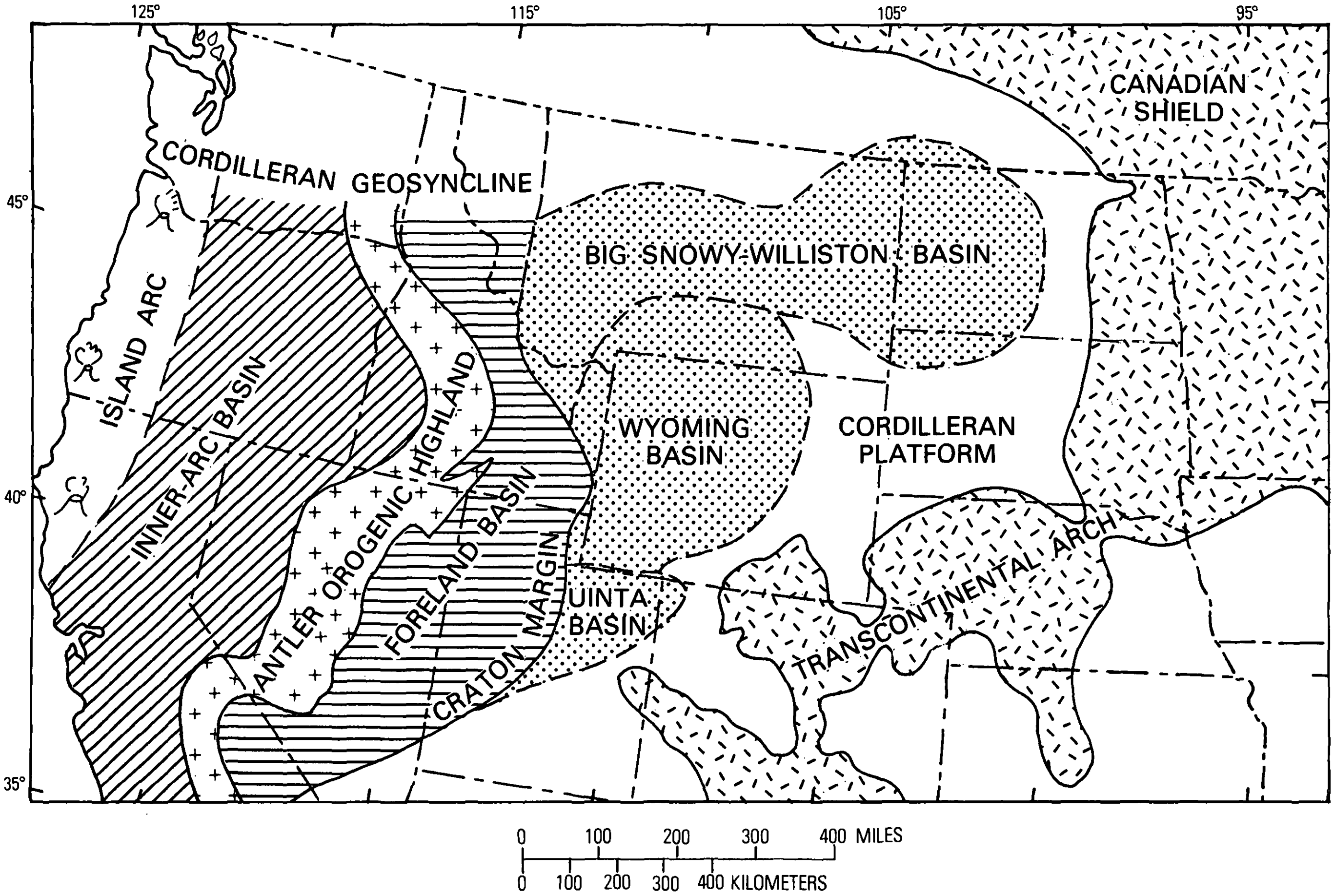


FIGURE 7.—Paleotectonic map of Carboniferous deposition in western United States. Modified from Sando (1976a) and Poole and Sandberg (1977).

Early Osagean (early Tournaisian) time marked the beginning of regression, characterized by westward progradation of shelf carbonate sediments (Madison Limestone). The foreland basin in Idaho became a starved basin that received fine terrigenous sediment (lower part of Little Flat Formation) during the latter part of the Osagean. Restricted circulation on the Cordilleran platform caused evaporite deposition during several periods beginning in the middle or late Osagean (middle or late Tournaisian) and extending into the early Meramecian (early Viséan). A reflux system associated with evaporite deposition caused dolomitization of underlying shelf carbonate rocks.

During latest early Meramecian (early middle Viséan) time, epeirogenic uplift drained the Cordilleran platform in Wyoming, while the foreland basin continued to receive marine sediments. A karst topography began to form in Wyoming, and a river system began to carry terrigenous sediment from the Transcontinental arch across the platform to the foreland basin.

Karst development continued throughout the Cordilleran platform until late Meramecian (late Viséan) time, when subsidence of the platform margin permitted encroachment of the Cordilleran sea into Wyoming and southwestern Montana. Shelf carbonate deposits began to form in the foreland basin and to prograde eastward. Continued subsidence caused the sea to transgress eastward in three developing basins, the Big Snowy-Williston basin in Montana, the Wyoming basin in Wyoming, and the Uinta basin in Utah and Colorado (fig. 7), each basin receiving terrigenous sediments from the Transcontinental arch on the east.

In Wyoming, a basal transgressive sand (Darwin Sandstone Member of the Amsden Formation and its equivalents), composed in part of reworked river sediment, was deposited across the Wyoming basin, filling irregularities and solution cavities in the underlying karst terrane. The sand was followed by an eastward-expanding red-bed facies (Horseshoe Shale Member of the Amsden Formation) deposited in a lagoonal environment, produced in part by restriction of the mouth of the Wyoming basin. The eastern margin of the eastward-prograding carbonate shelf of the foreland basin protruded into the mouth of the Wyoming basin in western Wyoming during middle Chesterian (late Viséan and early Namurian) time (Moffat Trail Limestone Member of the Amsden Formation). In late Chesterian (late Namurian) time, a restricted carbonate-terrigenous facies (Ranchester Limestone Member of the Amsden Formation) began to form at the mouth of the Wyoming basin.

The three facies of the upper depositional cycle—sandstone, red beds, and restricted carbonate-terrigenous rocks—continued to trangress eastward across the expanding Wyoming basin until Morrowan (latest Namurian and earliest Westphalian) time, when the shallow sea of the Wyoming basin breached a narrow land area that separated it from the Big Snowy-Williston basin in Montana. Hence, Pennsylvanian rocks rest disconformably on Mississippian rocks only in eastern Wyoming, where the upper depositional transgression did not cover the karst plain composed of lower depositional sequence rocks until Morrowan time. Expansion of the Wyoming basin continued into the Atokan (early Westphalian), followed by the influx of a flood of quartz sand (Tensleep Sandstone and equivalents) during later Atokan and later Pennsylvanian time.

PENNSYLVANIAN (UPPER CARBONIFEROUS) SYSTEM OF WYOMING

By Edwin K. Maughan

INTRODUCTION

Carboniferous rocks in Wyoming originated chiefly as marine sediments and are divided into lower, chiefly carbonate, deposits of Mississippian age, and upper, chiefly terrigenous, detrital sediments of Pennsylvanian age. Four cycles of deposition are recorded in these Carboniferous rocks, which accumulated upon the shelf between the North American craton and the Cordilleran miogeosyncline. The lower two depositional sequences, the Madison Limestone and the Big Snowy Group or their equivalents, are of Mississippian age; the upper two sequences, the Amsden Formation and the Tensleep Sandstone, or their equivalents, are of Pennsylvanian age. Regional unconformities separate the four sequences. Generally, red mudstone strata that mark the initial deposits of the Pennsylvanian rest unconformably either upon remnants of the upper Mississippian sequence, which comprises strata of Late Mississippian (Chesterian) age, or upon the lower Mississippian sequence, which comprises the Madison Limestone of Kinderhookian, Osagean, and Meramecian age. An exception is in the southern part of the Laramie and the Medicine Bow Ranges (fig. 8), where Pennsylvanian strata rest unconformably upon Precambrian rocks. The upper Pennsylvanian sequence generally rests unconformably upon strata of the lower Pennsylvanian sequence, but locally, erosion has completely stripped away the lower Pennsylvanian strata, and the upper sequence rests upon rocks as old as the Madison.

Upper Carboniferous strata are exposed along the flanks of most mountain ranges in the State and in thrust plates within the westernmost mountains (fig. 8). Drill logs and cores from boreholes in most structural basins provided lithologic and paleontologic data to establish continuity of the strata between outcrops throughout the State.

Pennsylvanian strata were deposited in Wyoming in shallow marine water of the continental shelf. Highlands of the ancestral Rocky Mountains lay to the south in Colorado, and a prong of these mountains, the ancestral Front Range (fig. 9), projected northwestward into south-central Wyoming approximately coincident with the present-day Sierra Madre. The low Siouxia landmass was east of Wyoming, but shallow seas between the ancestral Front Range and Siouxia extended through southeastern Wyoming and across eastern Colorado, western Nebraska, and Kansas into Oklahoma and the Ouachita geosyncline (McKee, Crosby, and others, 1975, pl. 15A). The Cordilleran miogeosyncline and related geanticlinal or island-arc areas lay to the west in central Idaho. Northward, in Montana lay a continuation of the shallow shelf where shoal deposits similar to those deposited on the shelf in Wyoming characterize most of the Pennsylvanian rocks. The Bannock highland (Williams, 1962) was a probable land area in southeastern Idaho and adjacent

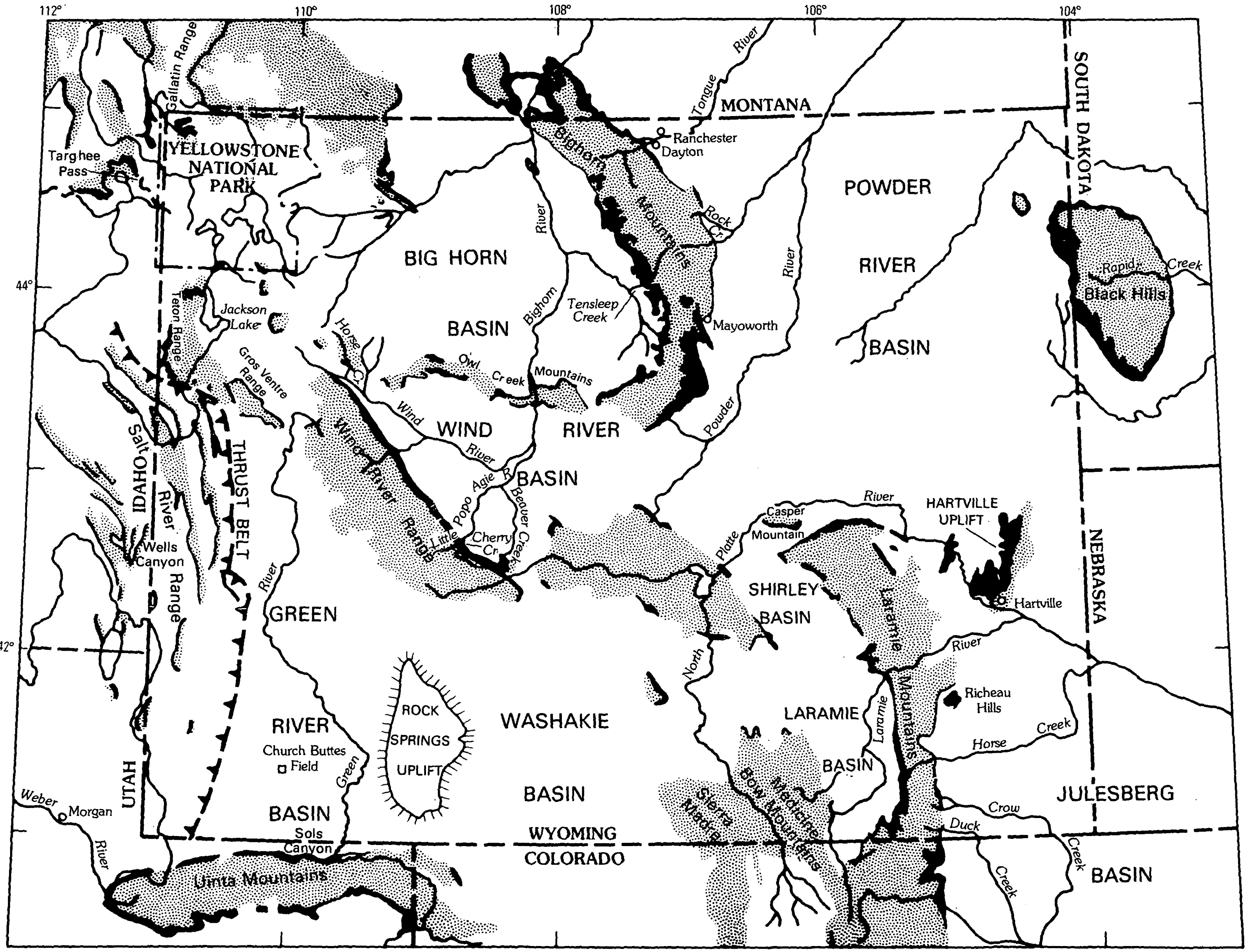


FIGURE 8.—Index to localities referred to in text. Outcrop of Pennsylvanian rocks shown in black and those of older rocks, by stipple pattern.

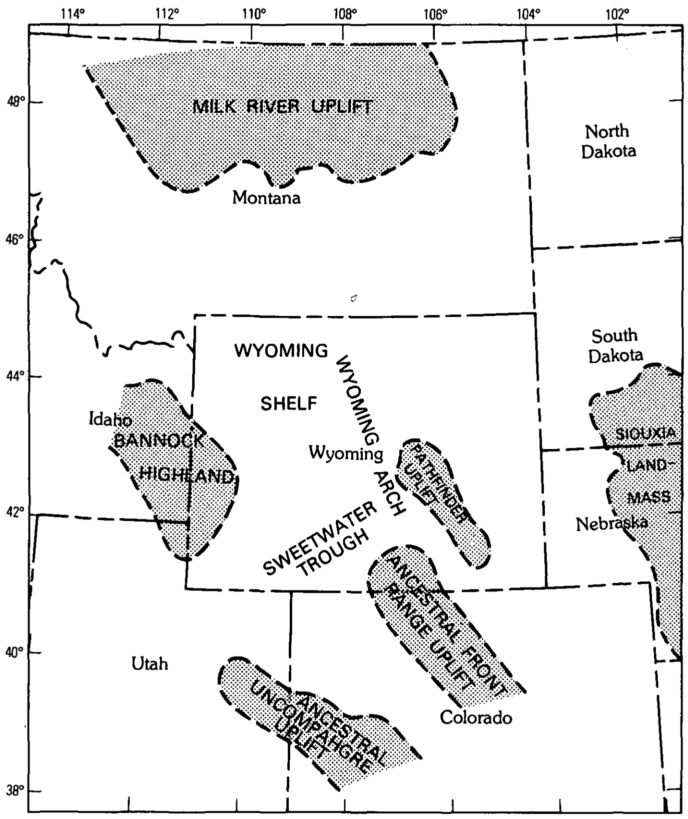


FIGURE 9.—Paleogeographic elements affecting deposition and preservation of Pennsylvanian rocks in Wyoming and adjacent States.

parts of western Wyoming in Early to Middle Pennsylvanian time, as was the Pathfinder uplift (Mallory, 1963) in east-central Wyoming; however, these land areas seem to have been low lying or were quickly eroded to base level and subsequently buried beneath sediments of the Upper Pennsylvanian sequence in Middle to Late Pennsylvanian time.

PREVIOUS WORK

Excellent summaries describing the Pennsylvanian rocks in most of Wyoming have been written by Williams (1962) and Mallory (1967, 1975). The present report is taken largely from these works, minor changes being drawn chiefly from newly available data or from slightly different interpretations of the data for which I am solely responsible. Other important contributions to the understanding of the vertical sequence and the lateral correlations of the Pennsylvanian rocks have been those of Condra, Reed, and Scherer (1940), who established correlations between surface exposures of the Minnelusa, Hartville, and Casper Formations; Love, Henbest, and Denson (1953), who carefully documented the fusulinids in the Hartville Formation; Love (1954), who correlated Pennsylvanian rocks in an east-west section in Wyoming; Agatston (1954), who summarized much surface and subsurface data of the Pennsylvanian rocks in northern and eastern Wyoming; and Foster (1958), who divided the Minnelusa Formation into three members bounded by regional unconformities and described the thickness and lithofacies of these members in northeastern Wyoming. Faunal data for the lower Pennsylvanian sequence and the lower part of the upper sequence were contributed by Sando, Gordon, and Dutro (1975). Many other investigations are referred to in the text where appropriate.

ACKNOWLEDGMENTS

I am grateful to H. D. Thomas, former Wyoming State Geologist, who initially encouraged my study and suggested answers to some of the questions regarding Pennsylvanian rocks in the Laramie Range and adjacent parts of southeastern Wyoming. F. F. Wilson helped to develop the concepts relative to the stratigraphic, paleogeographic, and tectonic framework along the northern Front Range in Colorado and in southeastern Wyoming; A. E. Roberts made similar contributions in Montana. Discussions with W. W. Mallory, H. R. Wanless, and J. D. Love were especially useful to test and extend these concepts in other parts of Wyoming. Many individuals and publications have provided fragments of information and have contributed to this report.

TECTONIC FRAMEWORK

Tectonic movements in Wyoming during the Pennsylvanian were subtle and seem to reflect epeirogeny peripherally related to strong orogenic disturbances in the mobile Cordilleran geosyncline. Repeated movement of the ancestral Rocky Mountains south of Wyoming also seems to have been approximately contemporaneous with orogenic movements in the geosyncline. Thus, low-magnitude epeirogenic adjustments in Wyoming that included arching, downwarping, and possibly faulting, subtly affected the provenance of the sediments, lithological constituents, environments of deposition, and preservation of the strata from place to place in the State.

Pennsylvanian deposition succeeded regional uplift, erosion, and karstification of the Mississippian strata. All of Wyoming seems to have been emergent at the beginning of the Pennsylvanian Period. Chesterian age rocks equivalent to the Big Snowy

Group of Montana and the Great Blue, Doughnut, and part of the Manning Canyon Formations of northern Utah are absent in most of the State, except for a wedge of Chesterian strata in the westernmost part and local remnants of the basal sandstone of the Chesterian sequence in the center and the east. Chesterian-age rocks of the upper Mississippian sequence probably were deposited across most of Wyoming; they were subsequently removed by erosion during latest Mississippian and Early Pennsylvanian uplift, except for basal sandstone remnants, which are the Darwin Sandstone Member of the Amsden Formation and the probably equivalent Fairbank Formation, in eastern Wyoming. In the western Wyoming thrust belt, the beveled wedge of these Upper Mississippian strata is preserved unconformably below Pennsylvanian strata where the Moffat Trail Limestone lies above red beds and sandstone strata that seem equivalent to the Darwin Member. Elsewhere in the State, where pre-Pennsylvanian uplift and erosion removed the Chesterian strata, Pennsylvanian rocks lie unconformably upon Kinkerhookian-to-Meramecian Madison or equivalent rocks. In southeastern Wyoming, in the vicinity of the ancestral Front Range uplift (fig. 9), Mississippian-age strata are entirely absent, and Pennsylvanian strata lie unconformably upon Precambrian rocks.

As the Pennsylvanian sea encroached upon the Wyoming shelf in late Morrowan time, paralic sedimentation gave way to marine littoral deposition across all of the State, except in the south-central part, where the northwest-projecting prong of the ancestral Front Range uplift remained. Initially, the upper Morrowan sediments, composed chiefly of highly oxidized and reworked soils that had formed during the Late Mississippian to Early Pennsylvanian uplift of the Wyoming shelf, were red terrigenous muds and very fine grained quartzose and arkosic sands deposited in shallow water of the advancing sea. However, carbonate sediments were the chief deposits in the Sweetwater trough (Mallory, 1975, p. 266) that projected northeastward from Utah into southwestern and central Wyoming. By early Atokan time, the sea had inundated the Wyoming shelf and adjacent parts of the cratonic margins along the Cordilleran geosyncline; the influx of terrigenous sediments was diminished, and carbonate sediments (chiefly lime mud) were widely deposited.

Middle to late Atokan time saw a second pulse of epeirogenic movement and renewed uplift that brought the ancestral Front Range and the ancestral Uncompahgre elements to their maximum relief. This Atokan epeirogeny was nearly contemporaneous with mid-Pennsylvanian orogenic movements in the mobile belt of the Cordilleran geosyncline in Nevada. The Wyoming shelf was warped and possibly locally faulted by this epeirogeny, so that other uplifts of low relief, such as the Bannock highland in western Wyoming and eastern Idaho (Williams, 1962, p. 159, 172) and the Pathfinder uplift in east-central Wyoming (Mallory, 1963), were rejuvenated or newly formed as parts of the ancestral Rocky Mountains. The previously formed Morrowan- and early Atokan-age sediments were stripped from these uplifts and were beveled in areas adjacent to them. Other areas that had been arched upward but had not necessarily been exposed above sea level were beveled also. Maximum relief of the Pathfinder uplift was probably about 150–200 m, as determined from the thickness of the earlier Pennsylvanian sediments preserved in adjacent downwarped areas and from the thickness of later Pennsylvanian sediments that lap onto the uplift. Uplift of the Bannock highland seems to have been of comparable magnitude, although it may have been as much as 300 m.

Deposition of the upper sequence of Pennsylvanian strata in Wyoming began at the time of the mid-Pennsylvanian epeirogeny. As the ancestral Rocky Mountains rose, sediments stripped from them were deposited in adjacent lows. These initial sediments of late Atokan to early Des Moinesian age were alternating beds of argillaceous and magnesian or lime mud and some thin beds of quartz sand. As the low areas filled and the uplifted areas were leveled in late Atokan and Des Moinesian time, quartz sand from distant sources to the west and northwest spread across western and central Wyoming to form an extensive sand blanket. Tongues of sand projected eastward from this large sand body into the alternating sand and carbonate sediments of eastern Wyoming. The ancestral Front Range uplift rose to its maximum relief and was a local source of arkosic sediment deposited at this time around the flanks of the uplift, but these ancient mountains probably contributed relatively little to the bulk of the sediments elsewhere in Wyoming.

Sand continued to be deposited in western and central Wyoming in Late Pennsylvanian time, but in eastern Wyoming, chiefly carbonate sediments were deposited during Missourian time and overlapped onto the Middle Pennsylvanian sand deposits of central Wyoming. This relation suggests diminishing delivery of sand from the western sources in Missourian time; however, another pulse of epeirogeny is recorded by an increase in the terrigenous components of the Virgilian sediments. This late Pennsylvanian epeirogeny led to the ending of Pennsylvanian deposition in Wyoming as uplift took place along a north-trending axis in central Wyoming, the Wyoming arch (Thomas, 1949). Virgilian-age sediments either were not deposited or were removed from most areas in the State, except in the far west and east. Missourian-age strata were entirely or mostly removed from the broad crest of the Wyoming arch, where rocks of Des Moinesian age are unconformably overlain by Permian strata.

Permian rocks record transgressive onlap of the Pennsylvanian strata on the Wyoming arch. Wolfcampian deposits occur in both western and eastern Wyoming, and sediments of probable late Wolfcampian to early Leonardian age were deposited thinly across a broad saddle on the arch in the central part of the State. Northward, the arch merged with the Milk River uplift in Montana (Maughan, 1966a), and southward it merged into the ancestral Front Range. Strata of late Leonardian age wedge out against higher parts of the arch in north-central and south-central Wyoming. Lower Guadalupian strata overlap the older Permian strata and rest on Pennsylvanian rocks in both northernmost Wyoming and adjacent parts of south-central Montana and in southernmost Wyoming and Colorado in the vicinity of the ancestral Front Range. The ancestral Front Range persisted as a land feature, and upper Permian strata rest unconformably upon Precambrian rocks beyond the limits of deposition of the Pennsylvanian strata on the flanks of this ancient land area.

STRATIGRAPHY

Pennsylvanian strata in Wyoming (fig. 10) comprise the Amsden Formation and the Tensleep Sandstone in the Bighorn Mountains and adjacent parts of central Wyoming westward to the Gros Ventre and Teton Ranges. In eastern Wyoming, they include part of the Minnelusa Formation in the Black Hills and adjacent basins, part of the Hartville Formation in the Hartville uplift, and part of the Casper Formation and the Fountain Formation in the Laramie Mountains. In southwestern Wyoming, Pennsylvanian rocks in the subsurface of the Green River basin include the Round Valley Limestone, Morgan Formation, and Weber Sandstone. In the ranges of the thrust belt in westernmost Wyoming, Pennsylvanian rocks are included in the Wells Formation. In the Gallatin Range in Yellowstone National Park, Pennsylvanian rocks comprise the Amsden Formation and Quadrant Quartzite.

CASPER, HARTVILLE, AND MINNELUSA FORMATIONS

The Casper, Hartville, and Minnelusa Formations are lithologically and sequentially similar and should be identified as a single formation. However, early studies and descriptions of these formations at isolated, widely separated exposures in the Laramie Mountains, the Hartville uplift, and the Black Hills have led to the use of separate names in each of these areas.

The Minnelusa Formation was the first to be studied. The name was initially used by Winchell (1875) and was later modified by Darton (1901) for the sandstone and limestone above the Pahasapa Limestone of Mississippian age and below the Opeche Shale of Permian age exposed along Rapid Creek in the Black Hills. Minnelusa is the Dakota Sioux name for Rapid Creek. Condra, Reed, and Scherer (1940) divided the Minnelusa into six units, which they correlated with similar divisions in the Hartville Formation. Two regional unconformities within the Minnelusa (fig. 10), provide boundaries for lower, middle, and upper members of this formation (Foster, 1958; Maughan, 1966b). The lower member of the Minnelusa is of Morrowan and Atokan age; the middle member is of Des Moinesian, Missourian, and Virgilian age; and the upper member is of Wolfcampian age.

The Hartville Formation was named by W. S. T. Smith (1903) for exposures of sandstone, carbonate rock, and mudstone between the Guernsey Limestone of Mississippian age and the Opeche Shale of Permian age in the hills around the town of Hartville, Wyo. Condra and Reed (1935) and Condra and others (1940) divided the Hartville into six units and gave names to them derived from geographic features in the vicinity of Guernsey Reservoir on the North Platte River in the Hartville uplift. They named the lowest unit the Fairbank Formation and designated the other units as "groups." The groups of Condra and others subsequently have been modified in rank, and the names have been used to identify members of the Hartville Formation (Tranter and Petter, 1963; Hoyt, 1963). The Fairbank Formation probably is of Mississippian age (Love and others, 1953). An informal threefold division into lower, middle, and upper members has been used (Maughan, 1966b, p. 97) and is adopted in this report in order to simplify comparisons with similar subdivisions of the Minnelusa and Casper

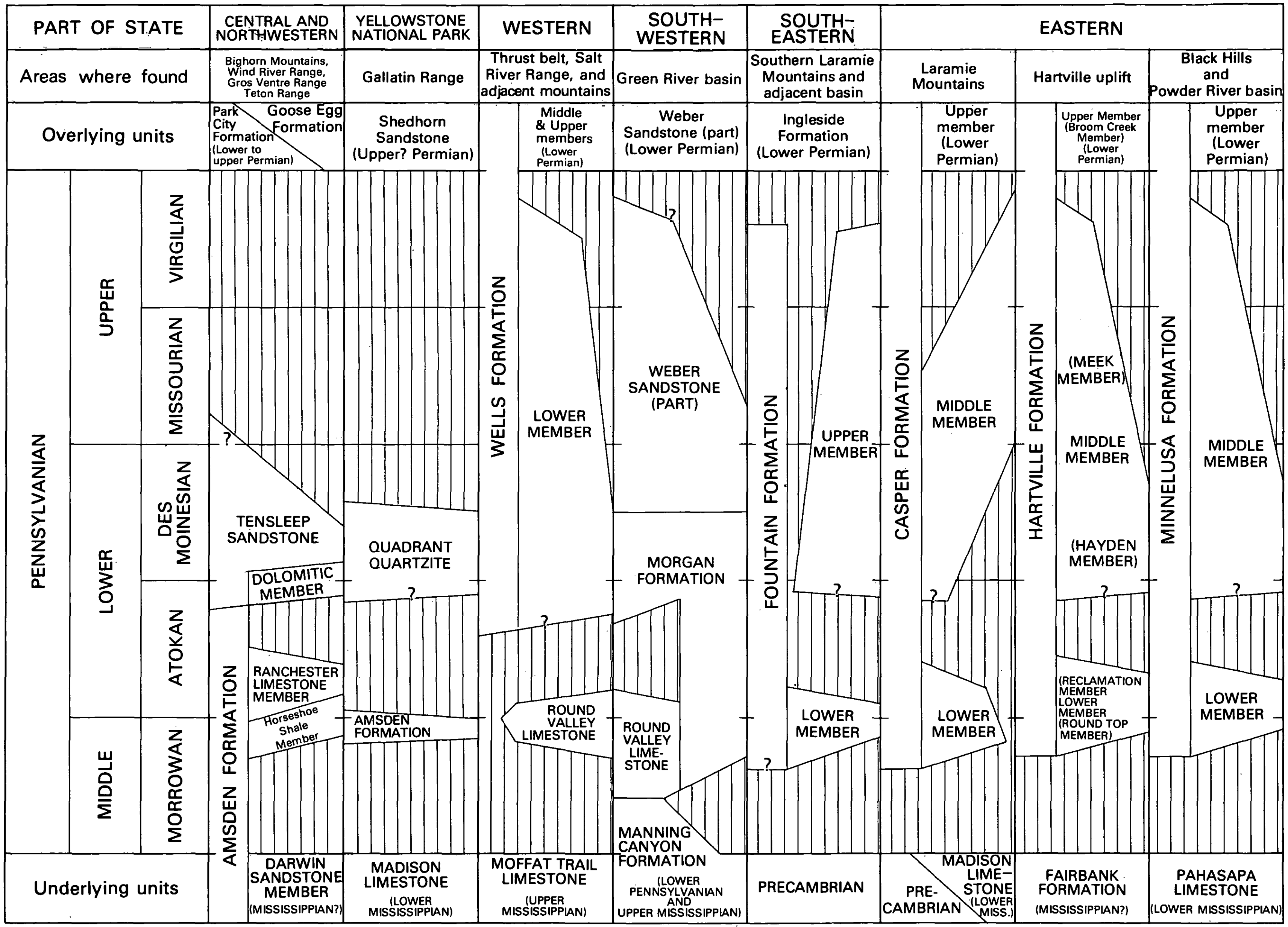


FIGURE 10.—Summary of nomenclature and correlation of Pennsylvanian rocks in Wyoming. Boundaries queried where ages uncertain; names in parentheses indicate usage of Tranter and Petter (1963).

Formations. The lower member, which excludes the Fairbank Formation and includes, in ascending order, the Reclamation and Roundtop Members of Tranter and Petter (1963), is of probable Morrowan and of Atokan age; the middle member, which includes the Hayden, Meek, and Wendover Members, is of Des Moinesian, Missourian, and Virgilian age; and the upper member, which includes the Broom Creek and Cassa Members, is of Lower Permian age (Love and others, 1953).

The Casper Formation was named by Darton (1908) for strata he believed to be equivalents in the Casper and Laramie Mountains of the Lower to Middle Pennsylvanian Amsden and Tensleep Formations. The Casper is more inclusive than Amsden and Tensleep as it also comprises strata of Late Pennsylvanian and Early Permian ages. In the southern Laramie Range, the Casper Formation lies unconformably upon Precambrian rocks, and in the northern part of the Laramie Range and on Casper Mountain, the formation is unconformable upon Madison Limestone of Early Mississippian age. The Casper Formation may be divided into three members similar in lithology and age to the members of the Hartville and Minnelusa Formations (Maughan, unpub. data, 1977). However, the lower member is absent at many places in the Laramie Range, and strata of the middle member ranging from Des Moinesian to Missourian in age form the base of the Casper Formation at these places. Onlap of the middle member northward along the west flank of the Laramie Mountains was recognized by Thomas and others (1953); similar onlap occurs on the east flank of the range. The lower member is present in outcrops along the east flank south of Horse Creek to the Colorado border, and probable remnants of the lower member are exposed at the base of the formation at places elsewhere in the range. The absence of the lower member and the onlapping of the middle member are evidence for the Pathfinder uplift. Uplift took place after deposition of the lower member. Remnants of the lower member that lie unconformably below the middle member must have formed prior to deposition of the onlapping middle member of the Casper. Members of the Casper Formation tongue southward into the lower and upper parts of the Fountain Formation of Pennsylvanian age and into the Ingleside Formation of Early Permian age in Colorado (Maughan and Wilson, 1960).

Basal strata in the Minnelusa, Hartville, and Casper Formations are chiefly red mudstone interstratified with fine-grained sandstone and thin beds of light-gray to pale-purple and pale-red-purple limestone. Detrital sediments predominate in the lowermost part of the Casper Formation because deposition took place near sources of terrigenous sediments in the ancestral Front Range; carbonate rocks predominate in the Minnelusa because of its more central position in the depositional basin. The mudstone and carbonate beds that constitute the lower member of these formations are commonly as thick as 70 m. However, thickness differs considerably from place to place, largely because of erosion prior to deposition of the overlying middle member. The lower member of the Casper Formation is beveled, and, locally, in the northern part of the Laramie Mountains, it is absent from the area of the Pathfinder uplift.

The limestone of the lower member is mostly light gray, although it commonly may be pale purple or pale red-purple. Commonly it contains red to dark-brown, white, and dark-gray nodules and stringers of chert. The limestone beds are generally 20–50 cm thick and are commonly interbedded with red or gray clayey mudstone ranging from a thin film to a few centimeters in thickness.

The late Morrowan and Atokan age of the lower member, which constitutes the lower Pennsylvanian sequence in eastern Wyoming, is best documented in sections of the Hartville Formation by the fusulinid zones of *Millerella*, *Profusulinella*, and *Fusulinella* (Love and others, 1953). *Millerella marblensis*, *Millerella pinguis*, *Profusulinella*, and *Fusulinella* (with one possible exception) are restricted to the lower member. *Millerella marblensis* and *M. pinguis* range through the lower part (Reclamation Member) and into the upper part (Roundtop Member) to an horizon about 34 m above the base of the lower member. *Profusulinella*, which is represented in a collection as low as 6.7 m above the base, indicates an Atokan age for the higher beds in the lower member; the lower 6 m probably is of Morrowan age. *Fusulinella* ranges from 10.5 m above the base to the top of the lower member, and the species represented indicate early Atokan age.

Fusulinella? cadyi, of Des Moinesian age, is an exception in the genus of *Fusulinella*, which usually indicates Atokan age. Love and others (1953) suggested that this Des Moinesian species may be regarded as possibly nearer the genus *Fusulina* than it is to the genus *Fusulinella*.

The lower member of the Casper Formation has not yielded fusulinids, although about 50 m of undated strata below the middle member on the eastern flank of the Laramie Mountains is presumably of early Atokan and Morrowan age. *Fusulinella* is represented in collections from the lower Minnelusa in the southern Black Hills (Thompson, 1936; Jennings, 1959), indicating a late Morrowan or early Atokan age of these strata in that area.

The middle member of the Casper, Hartville, and Minnelusa Formations comprises interbedded dolomite, calcareous cemented quartzose sandstone, and mudstone. Generally these strata are light to medium gray and yellowish gray, except in the Casper Formation where the middle member commonly is pinkish gray, especially in outcrops in the southern part of the Laramie Mountains. In that area, the strata tongue into the red arkosic upper member of the Fountain Formation.

Beds in the lower part of the middle member are mostly 20–50 cm thick, but in the upper part of the member they reach a maximum thickness of 10 m. Thin carbonaceous shale beds found in the lower part of the middle member in central eastern Wyoming are exposed in the Hartville uplift and in the southern Black Hills. These dark-gray carbonaceous shale beds grade laterally to pale olive green where exposed in the northern Black Hills and in the Laramie Mountains. In the subsurface of the southern Powder River basin, these carbonaceous strata are conspicuous on radioactivity logs.

Foraminifera from the upper Pennsylvanian sequence in eastern Wyoming indicate Des Moinesian to Virgilian age. *Fusulina* occurring as much as 54 m above the base of the middle member of the Hartville Formation indicates Des Moinesian age for the lower part of the member; *Wedekindellina ultimata* and cylindrical forms of *Triticites* indicate Missourian age for an approximately 40-m-thick middle part; and ventricose forms of *Triticites* indicate Virgilian age for as much as 20 m that constitutes the upper part of the middle member.

The zones of *Fusulina, Wedekindellina,* and of *Kansanella* (*Triticites* of cylindrical form) indicate the Des Moinesian to Missourian age of the middle member of the Casper Formation (Thomas and others, 1953; Thompson and Thomas, 1953; L. G. Henbest, written commun., 1964). Most collections from the lowermost strata of the middle member of the Casper are of possible late Atokan age according to Henbest (written commun., 1964). The zones of *Fusulina, Wedekindellina,* and *Kansanella* also occur in the middle member of the Minnelusa Formation (Thompson, 1936; Jennings, 1959; Verville and Thompson, 1963).

The upper member of the Minnelusa, Hartville, and Casper Formations is of Wolfcampian age and rests unconformably upon strata of the middle member, which in some areas are as old as Des Moinesian. At the base of the upper member in most of eastern Wyoming is a red sandy to argillaceous mudstone known as the red marker. This distinctive stratum, believed to be a regolith or redistributed regolith, marks an erosional contact between Pennsylvanian and Permian rocks. The red marker crops out in the southern Black Hills, the Hartville uplift, and the northern Laramie Mountains. The red marker is readily identified in subsurface logs in parts of the basins adjacent to surface exposures. The red marker extends northward to about the middle of the Powder River basin and seems to die out there and to the west on the eastern flank of the Wyoming arch, just short of surface exposures of this horizon on the southeast flank of the Bighorn Mountains. Its extent southward in the subsurface of the Julesberg basin is uncertain because of sparse drilling into Pennsylvanian rocks of southeastern Wyoming, but the red marker has been identified in westernmost Nebraska (Hoyt, 1963). Red beds similar to the red marker are found locally in subsurface logs of the Laramie basin and at the base of Permian rocks in some exposures on the flanks of the adjacent Medicine Bow Mountains, beyond the area in central Wyoming where the red marker seems to be regionally persistent.

FOUNTAIN FORMATION

The name Fountain Formation is used in south-central Wyoming for arkosic sandstone and mudstone of Pennsylvanian age where they crop out on the flanks of the southern part of the Laramie Mountains and in the Medicine Bow Mountains. This formation was named by Cross (1894) for red arkose exposed along Fountain Creek near Colorado Springs, Colo. The Fountain is exposed along the east flank of the Rocky Mountains in Colorado northward 230 km to the Wyoming State line. The Fountain Formation in Colorado is of Pennsylvanian and Early Permian age (Maughan and Wilson, 1960), and the rocks grade northward from alluvial-fan deposits through fan-delta sediments into littoral marine deposits. In the vicinity of Lyons, Colo., the Fountain is divided into three units: (1) the lower Fountain of probable Morrowan and Atokan age; (2) the upper Fountain north of Lyons of Des Moinesian to Virgilian age; and (3) part of the upper Fountain south of Lyons, which northward merges into the Ingleside Formation, of Wolfcampian age. The lower Fountain tongues into the lower member of the Casper Formation in Wyoming, the upper Fountain tongues into the middle member of the Casper in the vicinity of the Colorado-Wyoming State line, and the Ingleside merges into the upper member of the Casper (Maughan and Wilson, 1960).

ROUND VALLEY LIMESTONE

The Round Valley Limestone was named by Sadlick (1955, p. 56–57) for a thin-bedded limestone unit near Morgan, Utah, comprising rocks that lie unconformably above the Upper Mississippian Doughnut Formation and unconformably below the predominantly red mudstone and carbonate rocks of the Morgan Formation. The Manning Canyon shale of Mississippian and Pennsylvanian age conformably underlies the Round Valley at many places in the Wasatch Mountains and the Uinta Mountains in Utah, including the section at Sols Canyon (Anderman, 1955) illustrated in figure 11. The Round Valley previously had been included with the Morgan Formation, and this practice is currently followed in well logs that penetrate Pennsylvanian strata in southwestern Wyoming. Subsurface logs in the Green River basin show chiefly limestone in the lower Pennsylvanian (Verville and others, 1973; Verville and Momper, 1960, fig, 4, col. 2), assigned here to the Round Valley, which lies unconformably upon Mississippian limestone and below the restricted Morgan Formation. The Round Valley in Utah commonly has some red mudstone at the base and some dark-gray and locally reddish-brown mudstone in partings and thin layers interbedded with the thin-bedded limestone. The amount of interbedded mudstone in the formation increases eastward, and these rocks become mostly red mudstone eastward in the subsurface of the Green River basin. The strata gradually change from the dominant limestone facies of the Round Valley Limestone in southwestern Wyoming into the red mudstone and limestone facies that constitutes the Horseshoe Shale and Ranchester Limestone Members of the Amsden Formation in central Wyoming (fig. 11) and the lower member of the Casper Formation and equivalent strata in eastern Wyoming.

Foraminifera in the Round Valley Limestone belong in the zone of *Millerella* and indicate a Morrowan age for these rocks. Thompson (1945) identified *Millerella advena, M. inflecta, M. circuli, M.* cf. *M. pressa,* and *M.* aff. *M. marblensis* in the eastern Uinta Mountains from strata of the Round Valley Limestone that he called Belden Formation. Verville and Momper (1960) and Verville and others (1973) recognized the zone of *Millerella* and Morrowan age in rocks that are dominantly limestone in the lower part of the Morgan Formation in the subsurface of southwestern Wyoming. The zone of *Profusulinella* seems to be absent in southwestern Wyoming, although conodonts indicate that strata of early Atokan age are present, at least locally, in the subsurface of eastern Uinta County (Verville and others, 1973). Sadlick (1955, 1957, 1959) indicated an Early Pennsylvanian age, chiefly on the basis of brachiopod faunas in the Round Valley Limestone.

MORGAN FORMATION

The name Morgan Formation is commonly used in studies of the subsurface of southwestern Wyoming for Pennsylvanian rocks that lie unconformably upon the Mississippian Madison Limestone and that grade into overlying Middle Pennsylvanian Weber Sandstone. The formation was named by Blackwelder (1910) for exposures near Morgan, Utah, and the base was placed above a limestone unit of Pennsylvanian age, subsequently named the Round Valley Limestone (Sadlick, 1955). Gray limestone and black to dark-gray shale of the Round Valley Limestone have been included as basal strata of the Morgan Formation, as used in the subsurface of southwest Wyoming. Limestone beds of the Round Valley Formation have been excluded in this report from the Morgan of the subsurface; the restricted formation is like the Morgan at its type section and like outcrops along the flanks of the Uinta Mountains where the Morgan comprises reddish-brown sandstone, mudstone, and some dolomite or limestone. Sandstone is generally fine to medium grained, commonly calcareous, and white to light pink but weathers red. Dolomite and limestone beds are generally light gray, commonly cherty in white to gray and red to brown nodules and stringers.

The Morgan rests unconformably upon the Round Valley (Sadlick, 1955), and Sadlick (1957) considered the Morgan to be flysch derived from the ancestral Uncompahgre uplift. Williams (1962) suggested that sandstone and shale deposited at the type section is thicker than that deposited in the western Uinta Mountains because it was derived from the Bannock highland. He also stated that deposition of the Morgan took place in the Sweetwater trough between the Bannock and Uncompahgre land areas.

The Morgan Formation is of Middle Pennsylvanian age. The Hells Canyon Formation, an equivalent of the Morgan Formation on the southeastern

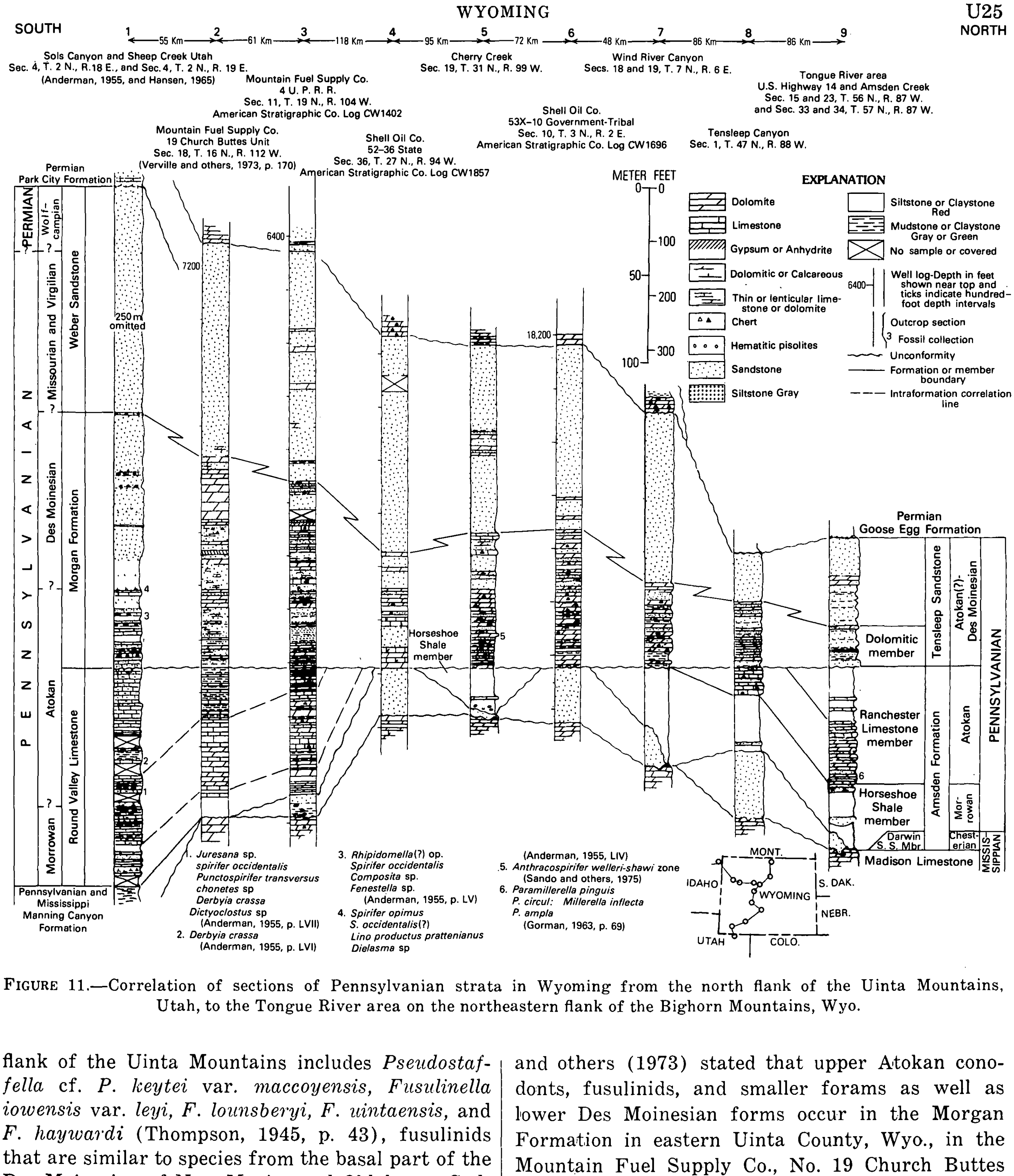


FIGURE 11.—Correlation of sections of Pennsylvanian strata in Wyoming from the north flank of the Uinta Mountains, Utah, to the Tongue River area on the northeastern flank of the Bighorn Mountains, Wyo.

flank of the Uinta Mountains includes *Pseudostaffella* cf. *P. keytei* var. *maccoyensis*, *Fusulinella iowensis* var. *leyi*, *F. lounsberyi*, *F. uintaensis*, and *F. haywardi* (Thompson, 1945, p. 43), fusulinids that are similar to species from the basal part of the Des Moinesian of New Mexico and Oklahoma. Sadlick (1955, 1957) and Kinney (1955, p. 43) assigned an early Des Moinesian age to the Morgan Formation. Sadlick (1955, p. 58) stated that "No fusulinids of Atokan age are known from [the Morgan Formation in] the Uinta Mountains." However, Verville and others (1973) stated that upper Atokan conodonts, fusulinids, and smaller forams as well as lower Des Moinesian forms occur in the Morgan Formation in eastern Uinta County, Wyo., in the Mountain Fuel Supply Co., No. 19 Church Buttes Unit well. Deposition of the Morgan strata probably was earlier in the Sweetwater trough than in areas of outcrop in the eastern Uinta and in the Wasatch Mountains—localities that were on the flanks of the ancient Uncompahgre and Bannock highlands.

WEBER SANDSTONE

The name Weber Sandstone (pronounced WEE-burr) is used in Wyoming in subsurface descriptions in the southwestern part of the State. The name was first used by Clarence King (1876) in referring to sandstone of the middle Coal Measures in Weber Canyon, Utah. Blackwelder (1910) defined the formation at a type locality in the upper narrows of the Weber River near Morgan, Utah, and described it as quartzite and sandstone lying above the redbeds of the Morgan Formation and below the dominantly carbonate rocks of the Permian Park City Formation. The Weber is exposed eastward of the type area on the flanks of the Uinta Mountains into northwestern Colorado. Age of the Weber in the type area is Middle (Des Moinesian) to Late Pennsylvanian, but in the Uinta Mountains, sandstone strata of Early Permian age are included (Bissell and Childs, 1958). Sandstone strata that commonly are identified as the Weber Sandstone in the subsurface of the Green River basin are indicated as ranging from about middle Des Moinesian to Early Permian in age (Verville and Momper, 1960).

WELLS FORMATION

Pennsylvanian rocks in the mountain ranges of the thrust belt in western Wyoming form the lower part of the Wells Formation. This formation was named by Mansfield (1927, p. 71) for sandy, cherty limestone and calcareous sandstone above the Mississippian Brazer Limestone and below the Permian Phosphoria Formation. The type section is in Wells Canyon, Caribou County, Idaho. The formation was divided by Mansfield into three members. The lower member, which constitutes the Pennsylvanian upper sequence in western Wyoming, is of Middle Pennsylvanian (Des Moinesian) age and the two upper members are of Lower Permian age, according to Williams (1962, p. 171). The Wells generally lies unconformably upon the Brazer Formation, but at places in eastern Idaho and western Wyoming, strata of the lower Pennsylvanian sequence intervene.

Local remnants of the lower Pennsylvanian sequence commonly are mapped with the Wells, although they consist of limestone and red mudstone beds that resemble the Round Valley Limestone and its equivalent, the Ranchester Limestone Member of the Amsden Formation. These remnants probably could be identified as Round Valley or Ranchester and mapped separately from the Wells. In eastern thrust plates of the thrust belt, red mudstone dominates over limestone in the lower part of these basal strata. These rocks are differentiated at some places into the Horseshoe Shale and Ranchester Limestone Members of the Amsden Formation.

The bulk of the Pennsylvanian rocks in the thrust belt are sandy carbonate rocks that are mostly sandy dolomite and dolomitic limestone interbedded with sandstone and mudstone that grade upward into mostly medium- to thick-bedded sandstone. For the most part, these rocks seem to be of Middle Pennsylvanian age, although some strata near the top of the sequence are Late Pennsylvanian (Wanless and others, 1955, p. 35) and are as young as Virgilian, as determined from sparse collections of fusulinids (G. J. Verville, oral commun., 1977).

The pattern of Middle Pennsylvanian deposition in western Wyoming seems to be like the pattern of deposition elsewhere in the northern Rocky Mountains region. The Upper Pennsylvanian sequence, consisting of part of the Wells Formation, was deposited upon an erosional unconformity succeeding mid-Pennsylvanian regional orogenic disturbance. At the type section of the formation in Wells Canyon, an area within the Bannock highland, Des Moinesian-age rocks lie unconformably upon Chesterian-age rocks (Williams, 1962). In the eastern part of the thrust belt, an area that would have been on the flank of the Bannock highland, the Wells Formation includes basal strata that have an Atokan age, probably late Atokan. In the Green River basin, an area within the Sweetwater trough, equivalent strata included in the Morgan Formation show little or no hiatus between late Atokan and underlying early Atokan strata (Verville and others, 1973), which indicates continuous or near continuous deposition from the Lower into the Upper Pennsylvanian sequence. These relations indicate transgressive overlap of middle Atokan to Des Moinesian strata from the trough onto the adjacent Bannock highland.

AMSDEN FORMATION

The Amsden Formation was named by Darton (1904). The Amsden comprises red shale, white to dark-gray limestone, and dolomitic limestone that lie unconformably upon the Madison Limestone and are overlain by the Tensleep Sandstone. The type locality is the vicinity of Amsden Creek, a tributary of the Tongue River, on the east flank of the Bighorn Mountains near Dayton, Wyo. Because of poor exposures, sparse fossils, and complex stratigraphic relations, the Amsden Formation remains the center of much controversy.

The Darwin Sandstone Member was added to the Amsden by Blackwelder (1918) for white-to-red sandstone unconformably resting upon the Madison Limestone. This sandstone was thought by him to grade into the overlying red shale. Blackwelder (1918, p. 442) indicated that the Darwin Member should be mapped separately from the overlying weakly resistant shale, sandstone, and limestone that compose the rest of the Amsden Formation.

A reference section for the Amsden on Amsden Creek, as described by Gorman (1963), is composed of four units: (1) the Darwin Sandstone Member at the base; (2) red mudstone, siltstone, and sandstone; (3) a dominantly carbonate rock unit; and (4) a dominantly clastic unit characterized by appreciable quartz sandstone and some shale and dolomite. Other sections in the type area were given by Agatston (1954, p. 569), who used the top of the carbonate rock unit as the top of the Amsden. Foster (1958) also showed an unconformity directly above the carbonate unit and correlated the Amsden with the lower member of the Minnelusa Formation; Maughan and Roberts (1967) showed correlation from the Amsden type locality with equivalent Pennsylvanian-age strata in central Montana; Mallory (1967) divided the Amsden above the Darwin into two parts and named the dominantly red mudstone lower part the Horseshoe Shale Member, and the dominantly carbonate rock upper part, the Ranchester Limestone Member; Sando and others (1975, p. A11) presented graphic comparisons of several measured sections of the Amsden in the type area.

The correlation of the Horseshoe and Ranchester Members by Sando and others (1975) with strata of late Meramecian and early Chesterian age in western Wyoming differs from the correlation presented in this report. The Moffat Trail Limestone and underlying red beds that include sandstone correlated with the Darwin are included by Sando and others (1975) as members of the Amsden Formation in the thrust belt. These rocks are a beveled wedge of the Upper Mississippian sequence of Chesterian age. They correlate lithologically, stratigraphically, and paleontologically with the similar Doughnut and Humbug Formations of northern Utah and the similar Big Snowy Formation of southwestern Montana. On the other hand, the Horseshoe Shale Member unconformably overlies the beveled upper Mississippian sequence (figs. 11, 12) and does not underlie or tongue into the Moffat Trail as shown by Sando and others (1975). Only the Darwin Sandstone extends east of the thrust belt, where it unconformably lies immediately beneath the Horseshoe Shale Member and is included as a member of the Amsden Formation. In the thrust belt in western Wyoming, the Chesterian-age red beds that include Darwin-like sandstone and the overlying Moffat Trail should not be included in the Amsden Formation.

The Darwin Sandstone Member comprises white to light-yellowish-gray, commonly red-stained, fine- to medium-grained, moderately sorted sandstone. Sand grains are mostly well-rounded to moderately well rounded quartz. Clay is common, and ferromagnesian grains range from sparse to abundant. The rock is weakly to moderately well cemented by calcite, and in places it is siliceous. Bedding consists mostly of low-angle cross laminae in planar beds as much as half a meter thick, but at most localities, crossbeds containing wedge-planar and trough crossbeds, having depositional dip angles as high as 20°, occur as sets that are as much as 3 m thick, and angles as high as 45° have been reported (Houlik, 1973, p. 503).

The Darwin Sandstone Member lies unconformably upon limestone beds of the Madison Group and was deposited above a karst surface on the Madison. It includes angular limestone blocks and fragments along the contact at most places. Red mudstone, siltstone, and sandstone as well as angular blocks and fragments of limestone occur as irregularly shaped cavern fillings that extend well downward into the upper part of the Madison. Terra rosa beneath sandstone at the base of the Darwin is uncommon, however, and at most places the quartzose sandstone rests directly upon the limestone.

The Darwin is unconformably overlain by red mudstone of the Horseshoe Shale Member. An unconformity above the Darwin is indicated in part by truncation of strata at the top of the member and by paleoweathering of the upper 10–50 cm of the sandstone. Most exposures of the weathered upper contact of the Darwin show moderate yellow staining not seen elsewhere in the sandstone, and weathering is evident at the top of the Darwin in cores from south-central Wyoming (Reynolds and others, 1975).

Thickness of the Darwin reaches a maximum of 50 m (Keefer and Van Lieu, 1966, p. B37), but the member is absent at many places throughout northwestern Wyoming, commonly within short distances of thick remnants of the sandstone. At the type section of the Amsden, Gorman (1963) indicated an unconformity 8.3 m above the base of the

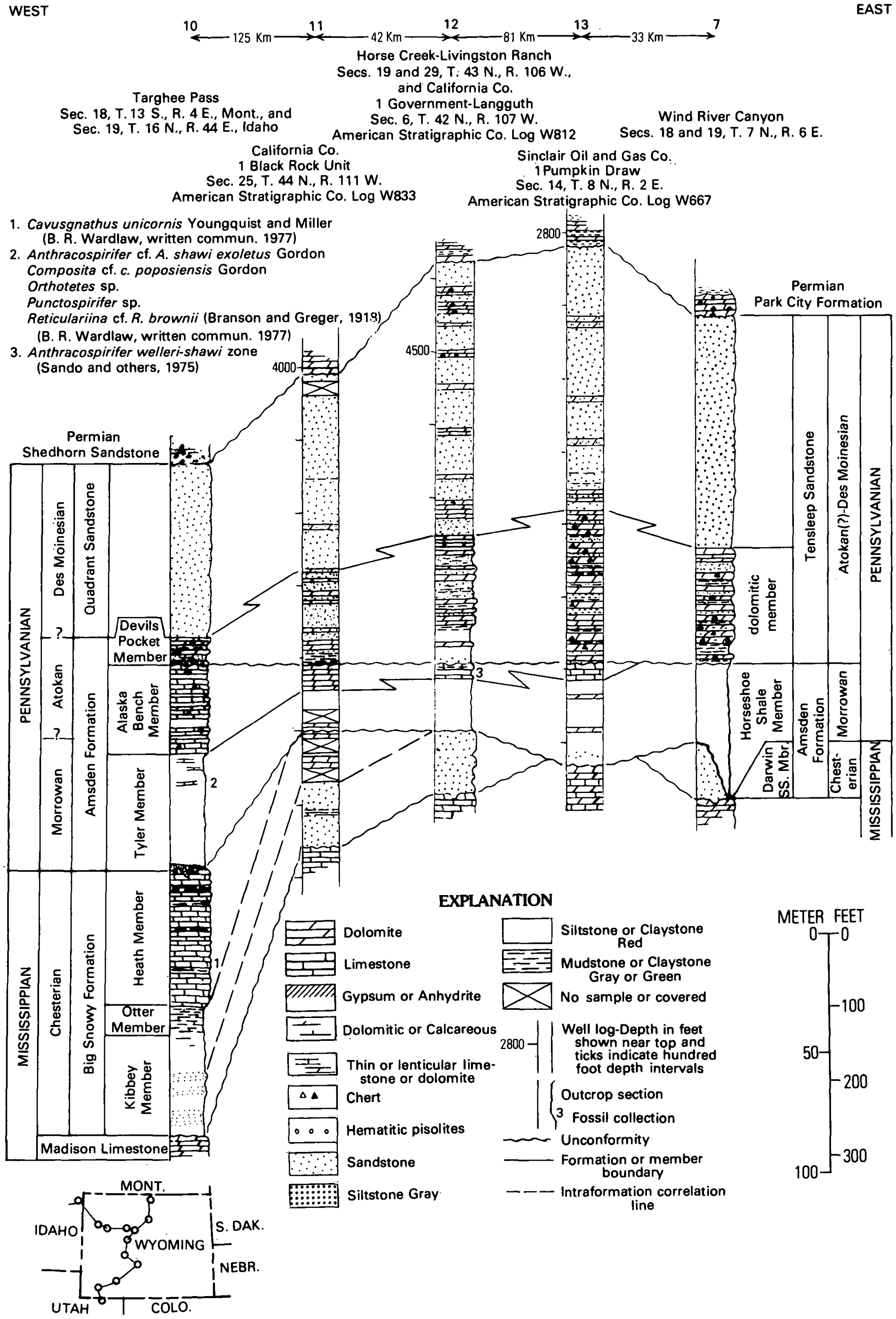


FIGURE 12.—Correlation of sections of Pennsylvanian rocks in northwestern Wyoming from Targhee Pass, Mont. and Idaho, to Wind River Canyon, Wyo.

Darwin. He indicated the total thickness of the Darwin as 13.1 m, but the Darwin-like sandstone above the unconformity is sand that seems to have been eroded from the Darwin and redeposited as a lensing channel-fill deposit in the base of the Horseshoe Shale Member. Because of erosion along this unconformable surface, the Darwin is absent 600 m west of Gorman's section, as shown by Maughan and Roberts (1967). Similar beveling of the Darwin Sandstone is evident in exposures of the Amsden in roadcuts along U.S. Highway 14 about 3 km southeast of the Amsden Creek locality. Beveling was recognized in the vicinity of Wind River Canyon (Maughan, 1972a, b), and it has been noted where the Darwin is locally absent in the vicinity of Horse Creek and Livingston Ranch in the Wind River basin and at many other places throughout the region.

Thickness variation of the Darwin has been attributed generally to deposition on the irregular erosional surface of the Madison (Agatston, 1954, p. 517; Keefer and Van Lieu, 1966, p. B37); however, the basal Darwin strata seem nearly conformable with the underlying Madison strata wherever the contact is not complicated by karst features (Houlik, 1973, p. 504–505). This applies even though the contact represents a significant hiatus, as indicated by the time required for the formation of karst and the regional transection of faunal zones in the Madison (Sando and others, 1975, p. A21). Most of the variation in the thickness of the Darwin is better attributed to erosional beveling at the top of the Darwin.

Age of the Darwin Member is considered to be Mississippian, probably early Chesterian, but this probable age determination is based on regional physical relations and lithologic similarities rather than on any direct paleontologic evidence. Fossils diagnostic of age have not been found in the Darwin. Brachiopods collected from the overlying Horseshoe Shale Member are believed to be of Pennsylvanian age, rather than Mississippian, as discussed elsewhere in this report. Thus, the age of the Darwin remains little less uncertain than when Blackwelder in 1918 (p. 423) noted that "the stratigraphic position of the sandstone indicates its age is early Pennsylvanian or late Mississippian—probably the former." Beds of sandstone that are very similar to the Darwin Sandstone compose part of an unconformable red-bed sequence that lies upon the Mississippian Madison Group and below limestone beds of Chesterian age in the western Wyoming thrust belt. This sandstone is correlated with the Darwin by Sando and others (1975).

Sandstone similar to the Darwin also makes up part of a red-bed sequence in the Kibbey Member of the Big Snowy Formation of Chesterian age, which lies upon the Madison Group in southwestern Montana and adjacent areas in Wyoming south of Yellowstone National Park (fig. 12, col. 10–12). These lithologically similar sandstones in the Big Snowy Formation, in the Chesterian of the thrust belt, and in the Darwin suggest that the strata are equivalent. Therefore, the age of the Darwin is probably Mississippian rather than Pennsylvanian. The correlation is possible only by comparing lithologic similarities, probably similar depositional environments, and regional stratigraphic relations.

The Horseshoe Shale Member of the Amsden Formation was named by Mallory (1967) and comprises chiefly red mudstone, siltstone, and fine-grained sandstone between the Darwin Sandstone Member and the overlying Ranchester Limestone Member at the principal reference section of the Amsden Formation. The name is from nearby Horseshoe Mountain, but the strata do not crop out there. Thin beds, generally less than 20 cm thick, of purplish- or reddish-gray argillaceous lime mud occur at some places, mostly in the upper part of the member. West of the type section, thin limestone beds are found within the member. Thickness of the Horseshoe generally ranges from 15 to 45 m, but the member is as much as 95 m thick near Casper and in the Shirley basin (Mallory, 1967, pl. 2B).

A few centimeters to a decimeter of pebble conglomerate may lie at the base of the Horseshoe Shale in northwestern Wyoming. Along Highway 14 on the northeast flank of the Bighorn Mountains, 24 m of medium-grained sandstone and mudstone, which originated as lenticular channel and overbank deposits, probably were derived chiefly from erosion of the Darwin. They constitute the lower part of the Horseshoe where it lies unconformably upon Madison Limestone and local remnants of the Darwin Sandstone Member. Above the channel and overbank deposits at Highway 14 and at most other places, the Horseshoe Shale Member mostly is composed of blocky to poorly fissile mudstone and siltstone and lesser amounts of clayey and very fine grained sandstone together with hematite and clay cement. Generally the member is covered with soil or talus and rarely is well exposed.

Pisolitic hematite, or possibly hematitic bauxite nodules, in beds that reach a maximum thickness of a meter, are common in the lower part of the member. The pisolitic beds lie at the base of the Horseshoe at many places; however, where channel and overbank deposits form the lower part of the member, the pisolitic beds, if present, lie between these and the overlying blocky mudstone that forms the upper part of the member. Biggs (1951, p. 21) suggested that the iron pisolites were formed in a shallow enclosed basin, an explanation similar to that proposed for deposition of the Silurian Clinton ores of the Appalachian region.

The Ranchester Limestone Member of the Amsden Formation was named by Mallory (1967) for the upper predominantly limestone part of the Amsden Formation at the principal reference section on Amsden Creek. The member is named for the town of Ranchester, about 16 km east of the type locality. The member comprises a lower predominantly limestone unit and an upper predominantly shaly unit. The Ranchester in the Tongue River area is unconformably overlain by sandstone, dolomite and shale strata that compose the lower part of the Tensleep Sandstone, although at most places in Wyoming, these overlying strata consist chiefly of dolomite and commonly are included in the Ranchester. In this report, these dolomitic strata are excluded from the Amsden Formation and are included as a dolomitic member of the Tensleep.

The Ranchester varies widely in thickness and at places is absent because of erosional beveling prior to deposition of the basal dolomitic member of the Tensleep. The Ranchester Limestone Member is part of the lower Pennsylvanian sequence. The unconformity above the Ranchester and beneath the dolomitic member was shown by Foster (1958) to extend throughout the Powder River basin and by Maughan and Roberts (1967), through Montana. This unconformity extends westward from the Bighorn Mountains and is an element in the Pennsylvanian strata in western Wyoming, as shown on the correlation of sections in Wyoming (figs. 11 and 12).

The Ranchester comprises mostly light- to medium-gray and reddish- to purplish-gray limestone and dolomitic limestone. Dolomite predominates at some places, but generally it is a minor component in this unit. The limestone beds are mostly 0.2–1.0 m thick and commonly are interstratified with red, at some places purplish, argillaceous mudstone that occurs as parting films or in thicknesses as great as 15 m. Limestone beds commonly contain nodules and stringers of red, brown, white, and dark-gray chert. The jasperoid chert is a useful lithologic key that aids identification of the member. Carbonate rock predominates where only the lower 20 m or so of the member is present, but in a few places, as at Amsden Creek and along Highway 14, 3 km southeast of the type section, the carbonate unit is about 45 m thick, and the upper part of the member comprises almost equal amounts of carbonate rock and mudstone. Quartzose sandstone rarely occurs in the Ranchester Limestone Member.

The Horseshoe Shale Member and the lower unit of the Ranchester Limestone Member correlate with the lower member of the Minnelusa Formation and lower member of the Hartville Formation (Foster, 1958) and constitute the lower Pennsylvanian sequence in central and northwestern Wyoming. Maughan and Roberts (1967, pl. 4) showed correlation of the Horseshoe and Ranchester with the lithologically similar Cameron Creek Member of the Tyler Formation and the Alaska Bench Limestone of Morrowan and early Atokan age in central Montana. Correlation of the Horseshoe and Ranchester members of the type locality of the Amsden Formation with the Pennsylvanian Round Valley Limestone in southwestern Wyoming and the Uinta Mountains is shown in figure 11. Similar stratigraphic relations westward to the Pennsylvanian Cameron Creek and Alaska Bench equivalents of the Amsden Formation in southwestern Montana are shown in figure 12.

Regional stratigraphic relations show that the Horseshoe in central Wyoming must be the same age as or slightly younger than equivalent red beds of late Morrowan to Atokan age in the lowermost member of the Hartville and Minnelusa Formations in eastern Wyoming and probably are slightly younger than limestone and red beds of Morrowan age in the Round Valley Limestone in southwestern Wyoming and northern Utah. That the Horseshoe Shale Member is younger is emphasized by onlapping of successively younger Lower Pennsylvanian conodont zones at the base of the Pennsylvanian strata from the Uinta Mountains northward into the Green River basin (G. J. Verville, oral commun., 1977). Paleogeographic evidence indicates that this onlapping probably continues to the outcrops at Cherry Creek near the southern end of the Wind River Range and into the Wind River basin, where the base of the Horseshoe Shale Member seems to be younger than the approximately equivalent Morrowan strata in the Green River basin and no older than about middle Morrowan. Similar physical onlapping of the Pennsylvanian Tyler Formation of the Amsden Group in central Montana with the Horseshoe Shale Member at Amsden Creek has been shown by Maughan and Roberts (1967, pl. 1).

The age of the Horseshoe Shale and the Ranchester is Morrowan, probably late Morrowan and early Atokan, although the members are sparsely dated paleontologically. Gorman (1963) identified fusulinids that characterize the zone of *Millerella* from limestone at the base of the Ranchester. These fusulinids are similar to the fauna from the same stratigraphic horizon in the Hartville uplift (Love and others, 1953). Fusulinids of the zone of *Millerella* also occur near the base of equivalent strata in central and southwestern Montana, where they are part of the Alaska Bench Limestone (Scott, 1945a,b; Mundt, 1956, p. 50). Early Pennsylvanian fossils occur on the east flank of the Bighorn Mountains within 1.5 m of the base of the Horseshoe at South Rock Creek (Sando and others, 1975, pl. 6) and 8 m above the base at U.S. Highway 14 (Gorman, 1963). Early Pennsylvanian age is indicated for the Horseshoe in the Wind River basin as the result of paleontological studies by Burk (1954) from collections made by Biggs (1951) 8.5 m above the base of the member at Beaver Creek, 8.7 m, at Cherry Creek, and 11.3 m, at Horse Creek.

The brachiopod assemblages from some Wyoming localities have been assigned a Mississippian age (Shaw and Bell, 1955; Shaw, 1955; Sando, 1967; Sando and others, 1975; Gordon, 1975). If these assemblages are of Mississippian age, they must be very late Chesterian; however, the Pennsylvanian age of the brachiopod faunas of the Horseshoe Shale Member in the Wind River basin is indicated by the regional relations shown in figures 11 and 12. As emphasized by Burk (1954, p. 4), the assemblages include many species known elsewhere in strata considered to be Pennsylvanian. Burk stated (p. 4) that "No genus or species is exclusively Mississippian or older" and "none of the previously identified faunas have a range which conflicts with a Pennsylvanian age for the Amsden." The Chesterian age assigned to faunal assemblages from the Horseshoe Shale and Ranchester Limestone Members collected at Cherry Creek (fig. 11) and at Livingston Ranch (fig. 12) on the flanks of the Wind River basin (Sando and others, 1975; Gordon, 1975) is at variance with the regional, physical-stratigraphic correlations presented in this report. The strata that have yielded the *Anthracospirifer welleri-shawi* faunal assemblage seem to be no older than middle Morrowan.

In agreement with the observations of Burk (1954), *Anthracospirifer welleri* (=*Spirifer welleri*) and other elements of the *A. welleri-shawi* zone have been identified in Pennsylvanian strata of the Morrowan to lower Atokan Cameron Creek Member of the Tyler Formation and Alaska Bench Limestone in the Big Snowy Mountains in central Montana (Maughan and Roberts, 1967). Elements of the *Anthracospirifer welleri-shaw* zone—*Anthracospirifer* cf. *A. shawi exoletus*, *Composita* cf. *C. poposiensis*, and *Reticulariina* cf. *R. brownii*—have also been identified (B. R. Wardlaw, written commun., 1978) from the Pennsylvanian Tyler equivalent of the Amsden Formation at Targhee Pass on the Montana-Idaho border (fig. 12, col. 10). *Pugnoides quinqueplecis* in several collections assigned to the *A. welleri-shawi* zone in Wyoming (Sando and others, 1975) has been found only in Pennsylvanian strata in central Montana (Maughan and Roberts, 1967, pl. 4). Thus, the *A. welleri-shawi* zone seems to be Early to Middle Pennsylvanian rather than Late Mississippian.

The age of the Horseshoe Shale Member at Berry Creek in the northern part of the Teton Range is considered to be Pennsylvanian, for the strata illustrate the same regional stratigraphic relations as at Targhee Pass and at Livingston Ranch. The Horseshoe at Berry Creek also includes the *A. welleri-shawi* zone in association with foraminiferal zone 19 of Mamet (Sando and others, 1975, p. A42). Zone 19, which correlates with the European *Homoceras* zone (Mamet, 1975, p. B6), had been thought to indicate a Late Mississippian age, even though this zone had not been identified in youngest beds of the type Chester in Illinois. The occurrence of foraminiferal zone 19 at Berry Creek probably confirms the Pennsylvanian age of these rocks because Lane (1977, p. 179) recently has shown that the *Rachistognathus primus* conodont zone occurs both in the base of the type Morrowan in Arkansas and in the *Homoceras* zone.

Assignment of a Mississippian age to the Horseshoe at Livingston Ranch (Sando and others, 1975), on the basis of foraminiferal data, is also contradictory to the regional correlations. All the taxa in the foraminiferal fauna listed from Livingston Ranch (Mamet, 1975, p. B9) also occur in collections of more diverse foraminiferal assemblages from the Moffat Trail Limestone of Chesterian age and from the Ranchester Limestone Member of early Atokan age. The Foraminifera designated as indicative of foraminiferal zone 18 at Livingston Ranch on the basis of the published list of taxa are not necessarily limited to the Late Mississippian (B. L. Skipp, oral. commun., 1978; P. L. Branckle, oral commun., 1978) and are not contradictory of a Pennsylvanian age.

TENSLEEP SANDSTONE

The Tensleep Sandstone was named by Darton (1904, p. 396–397) for sandstone above the Amsden Formation and below red beds that are now named Goose Egg Formation of Permian and Triassic age. The type section is in the canyon of Tensleep Creek on the western flank of the Bighorn Mountains. The formation comprises light-gray to yellowish-gray sandstone, medium-to coarsely crystalline pinkish to gray dolomite and dolomitic sandstone in mostly thick to massive beds. Dolomitic strata are mostly in the lower part of the formation, and in this report these beds are considered to be a dolomitic member of the Tensleep, although they have commonly been regarded as part of the Amsden Formation.

The dolomitic member comprises interbedded yellowish- to pinkish-gray and very light gray, fine- to medium-crystalline dolomite, green and red mudstone, and white to yellowish-gray, fine- and medium-grained quartzose sandstone. Dolomite generally predominates in the unit, but at some places, either sandstone or mudstone constitute the bulk of the rocks. Sandstone beds are increasingly abundant in upper parts of the unit. Greenish-gray to pale-green mudstone in beds as much as 0.5 m thick form a seemingly characteristic part of the lowermost few meters of this unit everywhere in Wyoming, although moderate-red to moderate-reddish-orange and pale-red-purple mudstone commonly occur at the base of the unit and may locally form basal red beds as much as 5 m thick. The dolomite unit reaches a maximum thickness of about 40 m, and pinkish, medium- to coarsely crystalline dolomite beds 2–4 m thick occur throughout the overlying Tensleep Sandstone.

Sandstone of the Tensleep comprises mostly fine- and medium-grained, well-sorted quartz sand. Both silica and carbonate minerals cement the sandstone; in a general way, siliceous cement dominates in the northwestern part of the State and carbonate cement dominates toward the southeast. Dolomite beds as much as 4 m thick occur in the upper part of the Tensleep, and at some places, these beds are at or near the top of the formation. Sandstone and dolomite beds in the lower part of the Tensleep range mostly from 2 to 5 m in thickness, and the sandstone commonly has small-scale, low-angle planar cross stratification. Beds reach a maximum thickness of 10 m in the upper part, and the sandstone includes a variety of crossbedding forms, including large-scale, high-angle, wedge-planar cross stratification indicative of offshore bar, beach, and aeolian dune deposits (Reynolds and others, 1975). Contorted crossbedding is commonly seen in the upper part of the Tensleep. In the Bighorn basin, transport of the sand was from the northwest (Todd, 1966), and this, as well as the regional geometry of the Tensleep and equivalent sandstone formations, suggests that the source of the sand was principally northwest of Wyoming, possibly from geanticlinal elements within the mobile belt of northern Idaho and adjacent areas (Maughan, 1975, p. 287–288).

Fusulinids of the zone of *Fusulina-Wedekindellina* indicate the Des Moinesian age of the Tensleep (Henbest, 1954, 1956; Agatston, 1954, p. 528), and Love (1954) has shown regional relations of the strata and fusulinid and other faunas from the Tensleep and associated strata. In a few places, an advanced form of *Profusulinella* in the lower part of the Tensleep suggests late Atokan age for the base of the formation (Henbest, 1956, p. 61, collections f–9791 and f–12103).

Rocks as young as late Des Moinesian may be included in the Tensleep Sandstone in western Wyoming (Love, 1954, col. 5), but those strata in far western Wyoming that have yielded fusulinids of Late Pennsylvanian age (Love, 1954, col. 3; Wanless and others, 1955, col. 19) are in the thrust belt, where the Des Moinesian and younger Pennsylvanian rocks are part of the Wells Formation (Schroeder, 1976; Jobin, 1972).

In the southeastern Bighorn Mountains, Pennsylvanian strata, possibly younger than Des Moinesian age (Mallory, 1967, p. G23), and Wolfcampian-age rocks are included in the Tensleep Sandstone near Mayoworth (Verville, 1957). There is no paleontological evidence in this area for either Missourian- or Virgilian-age rocks in the Tensleep, although a thicker section in this area suggests the possibility of Upper Pennsylvanian strata. Agatston (1954, p. 526) noted the increase in the number of limestone beds in the lower part of the Tensleep on the southeast flank of the Bighorn Mountains. Increase of limestone in this area can be attributed to gradation from the mostly sandstone facies of the Tensleep into the interbedded carbonate rock and sandstone facies of the middle member of the Minnelusa.

The Wolfcampian-age strata on the southeastern flank of the Bighorn Mountains (Verville, 1957) probably should not be included as part of the Tensleep Sandstone because these rocks unconformably overlie thick to massive crossbedded, slightly calcareous sandstone typical of the Tensleep, and the sandy strata above are of differing character. The Wolfcampian strata comprise thin planar beds of moderately to very dolomitic sandstone and sandy dolomite. They seem to be equivalent strata to the basal member (the "Nowood Member") of the Park City Formation (Maughan, 1967, p. 140) and probably could be identified as a tongue of the upper member of the Minnelusa. They should be separated from the Tensleep rather than incorporated as a local exception to the regionally established Des Moinesian age of the Tensleep Sandstone.

Pennsylvanian rocks of the upper sequence are overlain unconformably everywhere in Wyoming by rocks of Permian age.

ECONOMIC PRODUCTS FROM CARBONIFEROUS ROCKS

By David R. Lageson

The principal economic products from Carboniferous rocks in Wyoming are petroleum and high-calcium industrial limestone. Other commodities of minor importance include building stone and aggregate. Ground water from Mississippian limestones may have future economic importance in eastern Wyoming counties because of increasing demands for water in agriculture and in growing communities.

According to statistics of the Wyoming Oil & Gas Conservation Commission, oil and gas production from Mississippian reservoirs accounts for approximately 6 and 1 percent of the total oil and gas production in the State, respectively. Similarly, oil and gas production from Pennsylvanian reservoirs accounts for approximately 37 and 2 percent of the total State oil and gas production, respectively. Carboniferous strata have been, and will continue to be, important exploration targets for the petroleum industry in Wyoming. (See table 2.)

Table 2.—*Oil and gas production from Carboniferous reservoirs in Wyoming*

[Data from the Wyoming Oil & Gas Conservation Commission. These data represent 1975 production and were the most current available at the time this report was compiled. bbl, billion barrels; mfc, million cubic feet]

Formation	Calendar year oil production (bbls)	Year total-oil (percent)	Calendar year gas production (mcf × 1,000)	Year total-gas (percent)
Madison	8,756,540	6.44	3,119,545	0.97
Amsden	147,578	.11	92,184	.03
Tensleep	34,000,464	25.01	5,608,017	1.75
Minnelusa	15,414,228	11.34	301,309	.09
Morgan	47,506	.04	285,287	.09
Weber	338,576	.25	1,249,982	.39
Total	58,704,892	43.19	10,656,324	3.32
Total of all producing formations in Wyoming)	135,809,697	99.9	317,646,049	99.3

The exploration and development history of Carboniferous reservoirs in Wyoming has paralleled petroleum development in the Rocky Mountain region as a whole. Oil seeps and prominent "sheepherder" anticlines were the primary exploration targets during the late 1800's and early 1900's. Subsequently, as well control increased and as seismic technology became available, stratigraphic traps and seismic anomalies became exploration targets. More recently, deep drilling along basin axes and sophisticated stratigraphic prospects in wildcat areas are producing new discoveries. In addition, there may be considerable potential for petroleum in Carboniferous strata in the overthrust belt of western Wyoming, an area currently receiving a great deal of exploration interest.

The Powder River basin has produced significant quantities of petroleum from Pennsylvanian reservoirs. The Minnelusa Formation received intense exploration interest throughout the 1960's and, as a result, is currently producing oil from approximately 170 wells in the basin (Wyoming Oil & Gas Conservation Commission, 1975). Minnelusa traps typically result from either structural closure or truncation of reservoir beds over buried paleotopographic highs.

Mississippian limestones, although thus far unproductive in the Powder River basin, have excellent reservoir characteristics. Potential Mississippian reservoirs have not been adequately tested because of excessive depths (McGregor, 1972). However, many potentially productive anticlines along the basin margins have been flushed with fresh ground water, precluding the possibility of Mississippian production.

In the Bighorn basin, the Pennsylvanian Tensleep Sandstone is the principal oil producer. Anticlinal traps account for most of the Tensleep production in the basin; combination structural stratigraphic traps involve thinning or truncation of Tensleep reservoir beds at the post-Tensleep disconformity over large anticlines (Welden, 1972). Diagenetic modifications of the Tensleep Sandstone, including multiple-stage cementation, are very important in determining reservoir quality throughout the basin.

The Mississippian Madison Limestone, an excellent petroleum reservoir, is productive from several anticlines in the Bighorn basin. Drilling experience has shown that production from the Madison occurs only where the structural closure is greater than the thickness of the Phosphoria (Permian) to Madison interval (Weldon, 1972). Shale members of the Phosphoria Formation, which are rich in organic matter, appear to be the source rock for Paleozoic oil in the Bighorn basin.

In the Wind River basin, the Tensleep Sandstone is again one of the most productive reservoirs. Large asymmetric anticlinal traps along the west flank of the basin, where the Tensleep is the deepest productive horizon, produce most of the Tensleep oil (Benner, 1972).

Petroleum production from Carboniferous reservoirs across southern Wyoming has progressed sporadically. Tensleep production at Lost Soldier field was established in the 1920's. Mississippian oil was discovered at Lost Soldier in 1948. Gas production at Lost Soldier is now used to repressure the Tensleep reservoir after removal of condensate (Skeeters and Hale, 1972). Subsequent Tensleep discoveries include Hatfield, Baily Dome, and Sugar Creek, the last of which extended Pennsylvanian production south of Lost Soldier and west of Hatfield. Other Pennsylvanian reservoirs in southern Wyoming include Allen Lake, Medicine Bow, and Quealy Dome in the Hanna and Laramie basins. In the Green River basin of southwestern Wyoming, Paleozoic production is at prohibitive depths except on major structures (Skeeter and Hale, 1972). The Table Rock deep unit, a structure developed off the east flank of the Rock Springs uplift, is a significant gas discovery in the Madison and Weber Formations. Pennsylvanian sour gas was discovered in 1969 at Church Buttes field at a depth of 5,460 m. Mississippian strata have good reservoir qualities but have thus far produced only nonflammable gas.

High-calcium industrial limestone is another important commodity from Wyoming's Carboniferous rocks. The Mississippian Madison Limestone is the best potential source of high-calcium limestone in the State. High-calcium limestone is in demand in Wyoming for its use in refining sugar from sugar beets and in lime scrubber systems for air-pollution control of coal-fired electric-generating powerplants. In air-pollution control, approximately 100,000 tons of limestone would have to be mined each year to supply a 1000-MW generating plant, depending on variables such as heat value of the coal and purity of the limestone. As the use of Wyoming's coal increases, high-calcium-limestone production may also be expected to increase.

Pisolitic hematite from the Darwin Sandstone may have future economic value. Biggs (1951) has reported discontinuous lenses of pisolitic hematite 6–10.5 m above the base of the Darwin Sandstone along the northeast flank of the Wind River Mountains.

Ground water from the Madison Limestone in the Powder River basin is a questionable and disputed resource. A proposed project involving the removal of Madison water for use in a coal-slurry pipeline is questioned on the basis of the recharge ability of the Madison aquifer. Madison water might also have future significance in terms of the increasing water demands of agriculture and communities in eastern Wyoming. Many questions still remain to be answered before this resource becomes a reality.

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2001

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
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DD. Alaska, by J. Thomas Dutro, Jr.

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CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

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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

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