Pennsylvanian and Associated Rocks in Wyoming

By WILLIAM W. MALLORY

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A regional study of the extent, thickness, lithology, and stratigraphic relations of the Tensleep, Amsden, Casper, and Fountain Formations, with emphasis on origin, paleogeography, and paleotectonic implications

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

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By William W. Mallory

ABSTRACT

The Pennsylvanian System in the Middle Rocky Mountains of Wyoming is represented principally by the Amsden and Tensleep Formations. These grade eastward into the Minnelusa, Hartville, Casper, and Fountain Formations, and southward into the Weber and Morgan Formations. The Amsden Formation has three members: the Darwin Sandstone at the base, the Horseshoe Shale (new name) in the middle, and the Ranchester Limestone (new name) at the top. The Darwin is of Chester (Mississippian) age; the Horseshoe is of Chester and Morrow ages; and the Ranchester is of Morrow age at the base but is mostly of Atoka age.

The Tensleep Sandstone (and its equivalent, the Quadrant Quartzite, in the Yellowstone Park area) is entirely of Des Moines age in the Bighorn and Wind River Basins. In central Wyoming, however, the Tensleep contains beds of Missouri, Virgil, and Early Permian ages. The Minnelusa and Hartville Formations in the eastern part of the State contain interbedded sandstone, shale, and carbonate rock ranging in age from Morrow to Early Permian. The Casper is composed of sandstone and carbonate rock and grades southward into red arkosic conglomerate of the Fountain Formation in the Laramie basin and adjacent areas. The Casper and Fountain Formations also range in age from Morrow to Early Permian, but the older strata are missing in a wide area in central Wyoming where the Pathfinder uplift, the northernmost element of the Ancestral Rocky Mountains, dominated the paleogeographic scene.

In Late Mississippian time the Mississippian Madison Limestone was exposed throughout the area except in the Laramie basin and adjacent mountains, where the Precambrian basement rocks were exposed. A karst surface formed in many areas on the Madison in Late Mississippian time. In late Chester and perhaps early Morrow time, marine waters spread eastward across Wyoming from the geosyncline in southern Idaho and invaded the major valleys first and later covered nearly all the Madison terrane. The Darwin Sandstone Member of the Amsden, probably derived from an older sandstone in south-central Canada, was deposited in the resultant bay. Continued submergence and a change in the source and type of clastic sediments carried into the area resulted in the deposition of a nearly tabular layer, the red Horseshoe Shale Member of the Amsden. During very late Morrow and Atoka time, limestone was precipitated from a clear sea to form the Ranchester Limestone Member of the Amsden. In southeastern Wyoming, coarse red arkosic sediments shed from the north end of the Ancestral Front Range uplift and the southern part of the Pathfinder uplift were deposited in the Laramie basin area as the Fountain Formation.

In Des Moines time the Tensleep Sandstone was deposited on a broad marine shelf over most of the area, while limestone, sandstone, and shale of the Hartville and Minnelusa Formations were deposited in eastern Wyoming. Arkose was deposited in diminishing quantities in the Laramie basin area during Atoka, Des Moines, Missouri, and Virgil times. In Missouri and Virgil time, western Wyoming was emergent, and some sand derived from the Des Moines Tensleep there was removed and redeposited in central Wyoming.

The Pathfinder uplift had its greatest extent and elevation in Atoka time and was progressively submerged later in the Pennsylvanian. It ceased to exist in late Virgil or Early Permian time.

INTRODUCTION

LOCATION AND EXTENT OF THE AREA

The report area is the State of Wyoming except six counties on the east side of the State (Campbell, Crook, Weston, Niobrara, Goshen, and most of Laramie County) and the thrust belt along the west side (much of Lincoln County and parts of adjacent counties) (fig. 1). The area spans 4° of latitude (41°–45° N.) and 6° of longitude (105°–111° W.) and encompasses about 70,000 square miles. Physiographically it is dominated by the Middle Rocky Mountains.

SCOPE AND OBJECTIVES

The stratigraphy of the Pennsylvanian System in the Middle Rocky Mountain region is generally simple, but understanding of relationships has been complicated by several problems, most of which concern the Amsden Formation. The objective of this study was to achieve a regional synthesis of Pennsylvanian strata (and closely associated rocks of Chester age) in an effort to resolve inconsistencies in the literature. The study disclosed that when these strata are seen in regional perspective, an uncomplicated pattern is apparent, and their relation to strata of greater, lesser, and equivalent

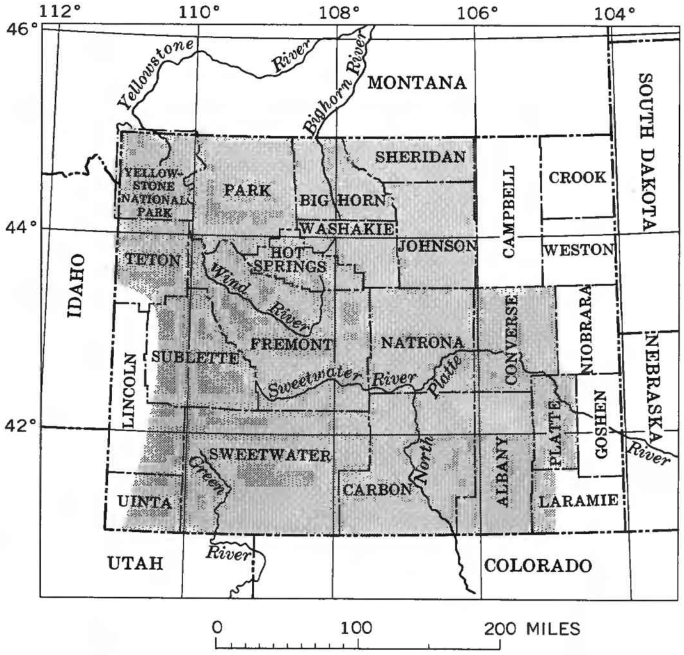

FIGURE 1.—Location of report area.

age can be demonstrated (pls. 1–3) with reasonable clarity.

PREVIOUS WORK AND ACKNOWLEDGMENTS

Previous work upon which correlation was based includes reports by Thomas, Thompson, and Harrison (1953), Love (1954; written commun., 1956), Henbest (1954, 1956, 1958a, b), Maughan and Wilson (1960), and Verville (1957).

Thomas, Thompson, and Harrison (1953) provided a clear and detailed exposition, in age sequence, of the lithology and distribution of the Pennsylvanian System in the Laramie Mountains area. Their plate 9, a series of correlated columnar sections showing fusulinid data, provides a key to correlation and stratigraphic mapping throughout southeastern and south-central Wyoming. Love's (1954; written commun., 1956) correlation diagrams, similar to those of Thomas, Thompson, and Harrison (1953), provide a correlation reference framework for western, central, and northern Wyoming. Henbest's papers on dating of the Amsden and Tensleep were helpful, particularly in the Bighorn Basin. Maughan and Wilson's (1960) sections of the Casper and Fountain Formations are a guide to the interrelation of these two formations. Verville's (1957) work in the Mayoworth area was significant in locating the Missouri, Virgil, and Wolfcamp subcrop limits in central Wyoming. Verville and Momper (1960) helped explain problems of the deep subsurface of southwestern Wyoming.

Parts of the correlation diagrams (stratigraphic sections, pl. 1) were taken directly from the work of these authors and were combined with measured sections collected from many sources and with sample logs of deep wells. Most of the well logs used were prepared by the American Stratigraphic Co. J. D. Love prepared several logs which were helpful. The sources of data are listed in the section, "Tabulation of Control Data."

In the summer of 1963, Ernest E. Glick assisted the author in measuring the type section of the Amsden Formation at Amsden Creek in the northeastern part of the Bighorn Mountains and the reference section of the Amsden at Tensleep Canyon.

METHODS OF STUDY

In the summer of 1959 the author examined all significant outcrop areas of Pennsylvanian rocks to gain firsthand familiarity with the strata and to augment study of the literature, measured sections, and subsurface data. Problem areas or areas of special geologic interest were examined in detail later.

The correlation of strata was based on similarity of lithology and vertical sequences of lithology; paleontologic data where available were used in dating and as a supplemental aid in correlation.

Post-Laramide erosion has exposed Pennsylvanian strata in many areas on the flanks of the Middle Rocky Mountains, and the presence of oil in the region has encouraged the drilling of many wildcat and pool wells in the sedimentary basins. The abundance of surface and subsurface control makes it possible to correlate the regional stratigraphy with confidence. In areas of facies change an effort was made, in constructing correlation diagrams, to select well logs or surface sections that contain the transition facies. Correlation of lithologic units within the Tensleep Sandstone is more difficult than correlation of the lithologically distinct members of the Amsden. Correlation is easiest in the Bighorn and Wind River Basins because there the Tensleep Formation contains strata of Des Moines age only. Farther east the Tensleep (and the equivalent Casper Formation) contains strata of Missouri, Virgil, and Wolfcamp age. However, careful comparison of surface sections that contain useful fossil evidence with well logs from adjacent basins permits correlations that give reasonable results.

To achieve consistent lithologic and time correlation, a network of correlation diagrams (stratigraphic sections) was constructed showing thickness, lithology, and age for control wells and sections. The cutoff date for incorporation of data into maps and sections was January 1, 1961. Areas where rocks older than Pennsylvanian are exposed are shown on the base map by absence of color or symbol. All maps are intended to be objective in that they show existing geologic relations and features instead of inferred original relations and features. The text discussion of each map contains comments, where appropriate, on inferred original depositional features.

Objectivity in subsurface isopleth maps is difficult to attain. Complete objectivity might be achieved by mechanically spacing all isopleths between available control. But, if additional control points were later incorporated, the new map would probably look radically different. Thus, the so-called objectivity would be false because the distribution pattern of the control points is treated as a mapping parameter.

Another method is to use the available control to detect trends or patterns which seem to be present and then to allow these suspected trends or patterns to influence the actual construction of the map. Such a map would be objective in that it showed a selected parameter, such as the thickness of a limestone. The map would be subjective to the extent that it contained trends or patterns that the mapper interprets.

In this report the author makes substantial use of interpretation of trend and pattern. Control points and parameter values are shown on all maps, so the reader may critically evaluate the author's interpretations or even make his own maps if he wishes.

The maps of western Wyoming accompanying this report are of lithologic units except for those units that encompass several ages of geologic time. The Amsden Formation consists of three members of distinctly different lithology, and each is mapped separately. The age of the lower (Darwin Sandstone Member) is Chester, that of the middle (Horseshoe Shale Member) is Chester and Morrow, and that of the upper (Ranchester Limestone Member) is Morrow and Atoka. The Tensleep Sandstone, on the other hand, is nearly homogeneous lithologically, but as it contains beds of Des Moines, Missouri, and Virgil age, the formation is divided on sections and maps as accurately as possible by age divisions. Formations in eastern Wyoming span Pennsylvanian time and are therefore mapped according to age, on appropriate plates.

Conventional colors are used to indicate lithology; yellow indicates sandstone (80 percent or more quartz sandstone), blue indicates carbonate rock (80 percent or more limestone or dolomite), and red indicates shale (80 percent or more shale or fine siltstone). Mixtures are shown by appropriate color combinations. For example, bluish-green indicates sandy carbonate rock, and yellowish-green indicates calcareous sandstone; browns indicate mixtures of the three end-members—carbonate rock, sandstone, and shale. (See explanation on plates.) In the selection of the colors to be used, the proportions of pure rock types at each control point for each unit mapped were quantitatively determined in 20 percent increments from pure end-members. A judgment factor of about 5 percent was introduced where reasonable to allow some leeway in drawing color-band boundaries.

TECTONIC SETTING OF THE MIDDLE ROCKY MOUNTAIN REGION IN PENNSYLVANIAN TIME

Throughout Paleozoic time the two major tectonic provinces in the western conterminous United States were the North American craton and the Cordilleran orthogeosyncline. Stille (1936, 1940) recognized within the geosyncline an inner belt adjacent to the craton (miogeosyncline) and an outer belt (eugeosyncline). During Pennsylvanian time most of what is now the State of Wyoming lay on the western margin of the craton; the extreme western edge of Wyoming extended a short distance into the miogeosynclinal belt (fig. 2).

Cratonic Western United States in Mississippian time was an unusually stable shelf over which marine waters advanced unimpeded. Tectonic activity in Pennsylvanian time, however, was greater in this region than at any other time between the Precambrian Era and the Laramide orogenic episodes of latest Cretaceous and Tertiary time. A chain of mountain ranges, the Ancestral Rocky Mountains, arose from the featureless Mississippian surface early in the Pennsylvanian Period in a belt which extended from central Wyoming to southern Oklahoma.

Four separate uplifts composed the Ancestral Rocky Mountains of the Western United States (fig. 2). The northernmost and smallest was the Pathfinder uplift in central Wyoming, which attained its widest areal extent in Atoka time (Mallory, 1963, p. E58). The large Ancestral Front Range uplift of central Colorado (Mallory, 1960, fig. 3) was part of a mountain chain that bifurcated in the subsurface into central New Mexico and southern Oklahoma (Rascoe, 1962, fig. 2). The Uncompahgre uplift which centered in southwestern Colorado may have attained along its southwest margin the highest elevation of all four uplifts. The Zuni-Defiance uplift in New Mexico and Arizona was a broad upwarp whose limits are not clearly defined.

The report area lies at the north terminus of the (Pennsylvanian) Ancestral Rocky Mountain tectonic complex. It includes the Pathfinder uplift, the northwest terminus of the Front Range uplift, and the cratonic Wyoming shelf, northwest of the Ancestral Rocky Mountains. This shelf was only mildly depressed in Pennsylvanian time in contrast with the strongly downwarped or downfaulted intermontane troughs and basins of Colorado and Utah.

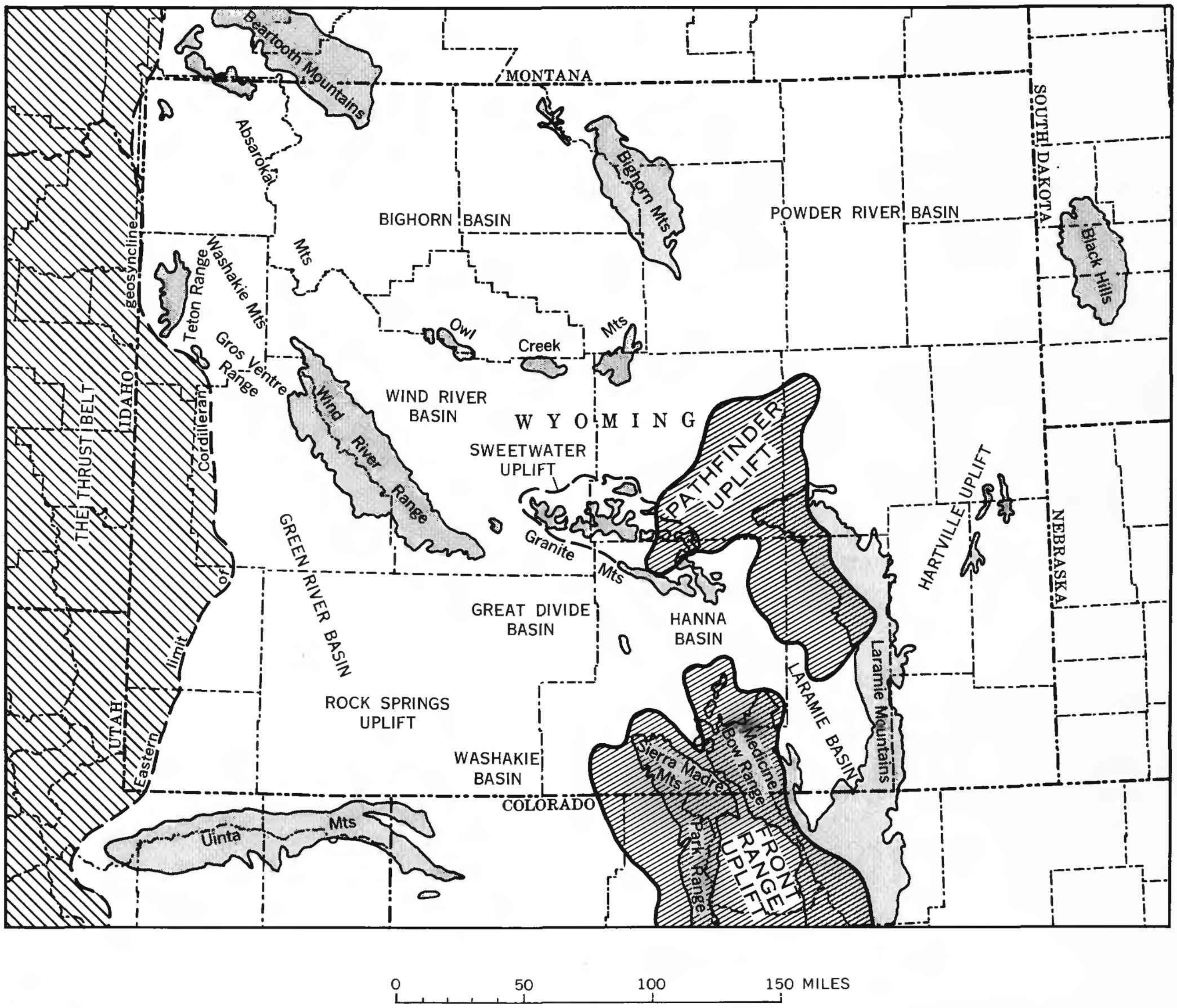

FIGURE 2.—Position of the Ancestral Rocky Mountains relative to existing ranges and basins in Wyoming. Existing mountain ranges are shaded; Pennsylvanian ranges are finely cross ruled. The east limit of the Cordilleran geosyncline in western Wyoming (coarsely cross ruled) is the limit of intense Laramide thrust faulting. In this province Pennsylvanian strata thicken markedly westward.

DEFINITION OF THE PENNSYLVANIAN SYSTEM IN WYOMING

The Pennsylvanian System in Wyoming comprises the following formations: Amsden, Tensleep, Quadrant, Casper, Fountain, Hartville, and Minnelusa (fig. 3). The uppermost parts of the Casper, Tensleep (in some areas), Hartville, and Minnelusa Formations are Early Permian (Wolfcamp) in age. The lower part of the Amsden is of Late Mississippian (Chester) age in at least part of Wyoming. The names Weber Sandstone and Morgan Formation have been used extensively in Utah and Colorado and are also appropriate in southern Sweetwater County, where these formations extend into Wyoming. The extent of the regions where each of these names is commonly used is shown in figure 4.

Nearly everywhere in the State, Pennsylvanian and closely related older strata rest disconformably on Mississippian or Precambrian rocks, and in many places the contact is exposed. In the Bighorn and Wind River Basins, where the Phosphoria Formation (of Permian age) commonly rests paraconformably (as defined by Dunbar and Rodgers, 1957, p. 119) on Middle Pennsylvanian Tensleep Sandstone, the upper boundary of the Pennsylvanian System is usually distinct owing to lithologic contrast. Elsewhere the Pennsylvanian-Permian boundary lies within the Tensleep Sandstone and

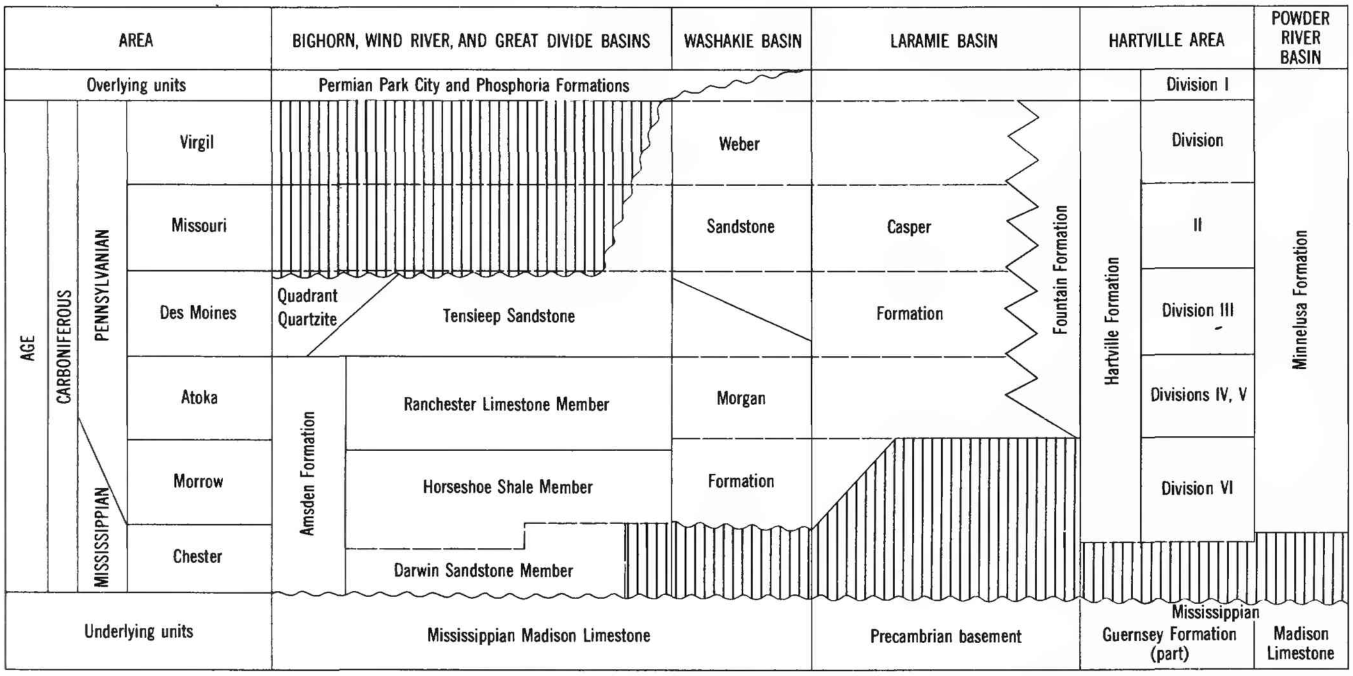

FIGURE 3.—Correlation chart of Pennsylvanian and closely related strata in Wyoming.

the Casper, Minnelusa, and Hartville Formations and is more difficult to determine.

EXTENT AND THICKNESS OF THE PENNSYLVANIAN SYSTEM

Rocks of Pennsylvanian age were deposited across all Wyoming except in the southeastern part occupied by the Ancestral Rocky Mountains. These rocks have been eroded from the crests of the Laramide uplifts but underlie the remainder of the region. Included among Laramide uplifts is the Sweetwater uplift (Cohee, 1961) in Natrona, Carbon, and Fremont Counties, where the absence of Pennsylvanian strata is not so obvious as on the major mountain ranges. Here Miocene strata rest on Precambrian basement rocks and partly bury the Granite Mountains.

The approximate mean thickness of the Pennsylvanian System and associated rocks of Mississippian age in the report area is 600 feet. The rocks are less than 500 feet thick in two areas (pl. 3(*D*)): the margins of the Ancestral Front Range and Pathfinder uplifts, and the Bighorn Basin–Montana boundary area, where these rocks thin into Montana and pinch out. Elsewhere they are 500–1,000 feet thick, except south of Jackson in northwestern Wyoming where they exceed 1,000 feet (thickening westward into the geosyncline) and in Sweetwater County where they thicken into the Eagle trough in Colorado and Utah. The area of thick Penn-

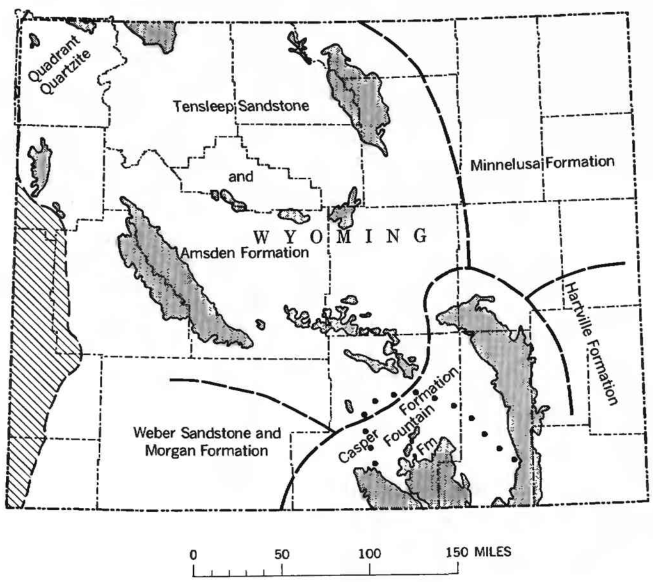

FIGURE 4.—Areal extent of Pennsylvanian formations in Wyoming. Boundaries are approximate. Exposed Precambrian rock in existing mountain ranges shown by shading; thrust belt shown by cross ruling.

sylvanian strata and strata of Chester age at Jackson extends eastward into the northern Wind River Range area in two elongate troughs. Near Laramie, between the Pathfinder and Front Range uplifts, a trough persisted after Morrow time and connected the Laramie and Denver basin areas.

LOWER BOUNDARY OF THE PENNSYLVANIAN SYSTEM

CHARACTER OF THE DISCONFORMITY

Nearly everywhere in Wyoming the Amsden, Casper, and Fountain Formations rest disconformably on the Madison Limestone. Locally in the Ancestral Rocky Mountains they rest nonconformably on Precambrian basement rocks. Typically, the buried Madison surface shows valleys, sinkholes, and caves. In Sinks Canyon, for example, a short distance west of Lander, Wyo., the Middle Popo Agie River flows for several hundred feet underground in a partly exhumed cave in the upper part of the Madison Limestone. In Wind River Canyon, south of Thermopolis, the highly irregular erosion surface on the top of the Madison is visible for several miles (fig. 5). The contact can also be seen in many of the

FIGURE 5.—Erosional disconformity between the Amsden Formation and the Madison Limestone in Wind River Canyon, south of Thermopolis, Wyo. The irregular heavy line emphasizes solution features of ancient karst topography being exhumed by Recent mass-wasting of the valley wall.

canyons on the flanks of the Bighorn Mountains. It is prominent and easily accessible at the entrance to Shell Canyon near Greybull and in many other places. In the northern part of the Wind River Range, however, the upper surface of the Madison is paraconformable with the overlying Darwin Sandstone Member, but a zone 40–50 feet below the top of the limestone contains abundant solution cavities now filled with material clearly derived from the Darwin and Horseshoe Members of the Amsden Formation.

In several localities on the flanks of the southern part of the Laramie Mountains, chert cobbles, probably derived from the Madison Limestone, were reported by Maughan (1963, p. C23). This observation suggests that the Madison extended over much or all of this area and was stripped away prior to deposition of the Fountain and Casper Formations on basement rocks. The findings by Chronic and Ferris (1961, 1963) increase the probability that other rocks of Paleozoic age older than Pennsylvanian were once widespread in southeast Wyoming and were removed by erosion prior to deposition of Pennsylvanian strata. Chronic and Ferris described two small structurally complex outliers (probably in diatremes) of unquestioned Ordovician and Silurian strata surrounded by a Precambrian granitic terrane of the Laramie Mountains near the Colorado border south of Laramie.

The character of the disconformity in the subsurface, however, cannot be inspected, but the gross configuration of the disconformity can be mapped indirectly from the thickness map of the Darwin Sandstone Member, which is based on data from deep wells. Because the Horseshoe Shale Member in the Wind River and Bighorn Basins has a nearly constant thickness over a wide area, it must closely approximate a tabular layer with nearly flat upper and lower surfaces. If the base of the Horseshoe is nearly flat, the top of the Darwin, on which it lies, must also be nearly flat. Hence, a thickness map of the Darwin must reflect irregularities of the Madison surface on which it rests.

Abundant evidence indicates that uplift of the Front Range and Pathfinder elements of the Ancestral Rocky Mountains in southeastern Wyoming was strong enough (particularly in Atoka time) to cause deposition of feldspathic fanglomerate in some adjacent areas of subsidence. Nevertheless, the author knows of no place where angular discordance between Pennsylvanian and Mississippian strata can be seen in the field. Absence of this relationship can be partly explained by the fact that in most of the areas where strong uplift took place Pennsylvanian strata rest directly on Precambrian igneous and metamorphic rocks. On the west side of the northern part of the Laramie Mountains, strata of the Casper Formation of Missouri age rest on Madison Limestone without visible angular discordance.

TIME SPAN OF THE HIATUS IN WYOMING

On the Wyoming shelf the hiatus beneath Upper Mississippian and Pennsylvanian rocks seems to represent a greater time interval in the eastern part of the State than in the western part near the geosyncline, as would be expected. In Bull Lake Canyon in the Wind River Range the age of the upper part of the Madison Limestone was determined by C. C. Branson (1937, p. 651, 653). Although he referred to a cavernous zone near the top of the Madison as the Sacajawea Formation, a fauna collected from this zone establishes its equivalence to rocks of late Osage or early Meramec age in the upper Mississippi Valley (W. J. Sando, written commun., 1965). Forty-five miles southeast, in the southern part of the Wind River Range, and at several other localities in western Wyoming, the oldest beds of the

Amsden Formation are of Chester age. (See p. G13 for a discussion of the age of the Horseshoe Shale Member at Cherry Creek.) Hence, evidence indicates that the disconformity at the base of the Amsden is intra-Mississippian.

In the Laramie Mountains area the upper part of the Madison Limestone is of Osage age or older (Maughan, 1963, p. C26). In the subsurface there, rocks of Morrow or younger age rest on the Madison. In exposures in the northern part of the Laramie Mountains, strata of Missouri age or younger locally rest on the Madison (Thomas and others, 1953, pl. 9). In the southern part of the range, Pennsylvanian strata rest on rocks of Precambrian age. Hence, rocks of Morrow to Missouri age rest on rocks of Mississippian or Precambrian age in southeastern Wyoming.

PALEOGEOMORPHOLOGY OF THE DISCONFORMITY IN NORTHWESTERN WYOMING

In the Bighorn and Wind River Basins of northwest Wyoming, tectonic emergence in immediate post-Madison time allowed the forces of mass-wasting and erosion to assume the major role in shaping the interface between the Madison Limestone and overlying rocks. Field inspection of the surface of disconformity at the top of the Madison in Wind River Canyon, Shell Canyon, and other canyons in the region suggests that a surface having tens of feet of relief is present over a wide area. The narrow dendritic areas which resemble stream valleys on the Darwin isopach map (pl. 2(*A*)) contain thick Darwin, and the broad areas that resemble hills or interfluves contain thin Darwin. The isopach index numbers show that the thickness of rocks of Chester age in this region generally ranges from a few tens of feet to 100 feet. The topographic pattern of Darwin isopachs in northwestern Wyoming is therefore ascribed to deposition on the dissected upper surface of the Madison Limestone.

If the isopachs on plate 2(*A*) are a reasonably valid representation of the regional topography developed in Late Mississippian time on the Madison Limestone in the Bighorn–Wind River region, then the most prominent topographic feature in the area at that time was a broad valley trending nearly east in the west-central part of the State. North and south of this valley are areas which apparently were so dissected as to represent late youth or early maturity. (If adequate control data were available for a local area, mesas formed by the original top of the Madison Limestone might be discovered. Such mesas, for example, are present on the dolomite of the Arbuckle Group beneath the Cherokee Shale in central Kansas.) Available evidence indicates that dissection resulted both from surface weathering and erosion and from solution at depth, forming caves. Ancient caves in the Madison filled with material derived from the Darwin and Horseshoe Members are found in several localities in the Rocky Mountain region.

For convenient reference, the ancient stream which flowed in this east-trending valley is herein termed the "Wyoming River" (pl. 2(*A*)). This river apparently entered the area in southern Johnson County and flowed west as a consequent stream down a regional slope presumably caused by broad epeirogenic arching of a wide region east of the area. Thickness values for the Darwin Sandstone Member in northwestern Fremont and southern Teton Counties indicate that the Wyoming River flowed in a valley 1–2 miles wide and about 200 feet deep. Farther upstream, control data are too sparse to define precisely the location and shape of the actual valley. In pre-Darwin time the Wyoming River flowed across the present Wind River Basin, the north end of the Wind River Range, and the Jackson Hole country, and debouched into the ocean in the Cordilleran geosyncline probably in eastern Idaho. Tributaries north and south of the river presumably formed a dendritic pattern in the flat-lying Madison Limestone. The texture of the topography as shown on plate 2(*A*) reflects only the density of the control net available for mapping. Actual texture can probably best be estimated by inspection of the disconformity in canyon walls, a surface which suggests that local features were small and similar to those of a karst topography (fig. 5). Later the sea advanced eastward into the estuary or bay formed by the valley of the Wyoming River.

INTERREGIONAL SIGNIFICANCE OF THE DISCONFORMITY ON THE CRATON

A comprehensive grouping and classification of cratonic sedimentary strata in North America was made by Sloss (1963). He defined (p. 95) and discussed the term "interregional unconformity" as follows:

> Only a very small number of the unconformities observable in the cratonic interior of North America can be shown to be truly interregional. When studied in the field or in the subsurface these exhibit no obvious characteristics within a limited area of observation which make it possible to separate them from other unconformities. * * * The most important criteria for the recognition of an interregional unconformity are the magnitude of its geographic scope and its persistence in previously and subsequently subsiding basins. * * * Only when the outcrop belts are integrated through the application of subsurface data and by the recognition of widespread lithic units of time-stratigraphic significance on a regional and interregional scale is it possible to identify interregional unconformities.

Abundant surface and subsurface evidence throughout the Central and Western United States indicates that the disconformity at the base of the Amsden, Casper, Hartville, Minnelusa, and Fountain Formations in Wyoming has interregional significance (Sloss, 1963, p. 102–104, figs. 3, 6; Henbest, 1958b, p. 37–38; Mallory, 1960, p. 23; Kellett, 1932; Walters, 1946, 1958). This hiatus was clearly defined on a continental scale by Sloss (1963, p. 102–3, fig. 6). He referred to it as the unconformity at the base of his Absaroka sequence, a craton-wide grouping of sedimentary rocks which includes upper Mississippian, Pennsylvanian, and younger rocks. Pennsylvanian strata form the base of the sequence over wide areas in the Central United States. The disconformity is present in the Mississippi Valley, midcontinent, Rocky Mountain, and Colorado Plateaus regions. In much of this vast cratonic territory, the rocks beneath Pennsylvanian strata are limestone (widely of Mississippian age but commonly older) upon which a surface with relief of scores or even hundreds of feet was developed. The form of the surface on carbonate strata is commonly karst in a stage of late youth to early maturity. (See Walters (1946, fig. 7, pl. 1) for a typical example in central Kansas.) Although the erosional surface undoubtedly was once physically continuous from central Ohio, Kentucky, and Tennessee to Montana, Wyoming, and Colorado, the duration of subaerial weathering in the cratonic United States was not everywhere the same.

In the orthogeosynclines (Appalachian, Ouachitan, and Cordilleran), deposition seems to have been continuous. In most areas, establishing the Mississippian-Pennsylvanian contact is difficult. Marine waters began their transgression from the orthogeosynclines over the continental interior during Chester and Morrow time and spread gradually over the peripheral parts of the craton. By Middle Pennsylvanian time most of the United States had been inundated. The higher, central part of the region was submerged last, allowing pre-Pennsylvanian rocks in these areas to weather longest. In parts of Kansas and Nebraska, for example, where strata of Des Moines age lie on rocks of Mississippian to Precambrian age over wide areas, weathering and erosion lasted through Atoka and Morrow time and probably much or all of Chester time.

In the Wyoming thrust belt and eastern Idaho, Mississippian fossils are found above sandstone which has been correlated with the Darwin of the Wind River Range area (Wanless and others, 1955, p. 31–34; Sando and Dutro, 1960, p. 125).

AMSDEN FORMATION

LITHOLOGIC UNITS

Darton (1904, p. 396–397) named the Amsden Formation for exposures on Amsden Creek, a small tributary of the Tongue River northwest of Dayton (sec. 32, T. 57 N., R. 86 W.), Sheridan County, Wyo. In 1906 Darton (p. 31) described the Amsden in greater detail as follows:

> * * * Throughout the Bighorn Mountains there is at or near the base of the formation a deposit of red shale, which lies directly on the upper limestone of the Madison formation, except locally to the south, where it is separated by a bed of brown or gray sandstone. Above the red shale there is a variable succession of pure, white, fine-grained, compact limestone, gray to brownish sandstones, red shales, and cherty limestones. At the top there usually are slabby sandstones, especially to the southwest where they take the place of the greater part of the limestone beds.
>
> The local basal sandstone above referred to attains its maximum development in the canyons of Otter Creek, where it has a thickness of 80 feet. In the vicinity of Tensleep Canyon its thickness is over 40 feet. It is coarse grained, of gray color, and cross-bedded * * *

The basal sandstone of the lower unit in northwestern Wyoming was named the Darwin Sandstone Member of the Amsden by Blackwelder (1918, p. 422–423) after Darwin Peak in the Gros Ventre Range, which is capped by this sandstone. (In Blackwelder's paper the name is spelled "Dorwin," presumably a typographical error.)

The nomenclature of Darton and Blackwelder is well suited to the Amsden Formation throughout the Middle Rocky Mountain region and can be applied even to superficially atypical sections like those at Bull Lake and Dinwoody Canyons. The three lithologic divisions of the Amsden described by Darton have been referred to as the Darwin Sandstone Member, the middle red shale unit, and the upper cherty limestone unit. To facilitate reference to the latter two units, and to reinforce the identity and stratigraphic relations of the units within the Amsden as established by Darton, new names are here introduced for the two unnamed units of the Amsden Formation above the Darwin. The name Horseshoe Shale Member is proposed here for the middle red shale. This name is taken from Horseshoe Mountain (sec. 27, T. 56 N., R. 87 W.) 7 miles southwest of Dayton. The type section of the Horseshoe Shale Member is in the SE¼ sec. 33, T. 57N., R. 87 W., on Amsden Creek 4 miles west of Dayton. The name Ranchester Limestone Member of the Amsden Formation is proposed here for the upper cherty limestone unit of the Amsden. The name is taken from the town of Ranchester (secs. 18–19, T. 57 N., R. 85 W.) 6 miles northeast of Dayton. The type section of the Ranchester Member is at the same location as that of the Horseshoe. A graphic section of these two members measured at Amsden Creek is shown in figure 6. Because the Darwin Sandstone Member is locally absent at Amsden Creek, the Horseshoe and Ranchester Members compose the total Amsden Formation at the type section.

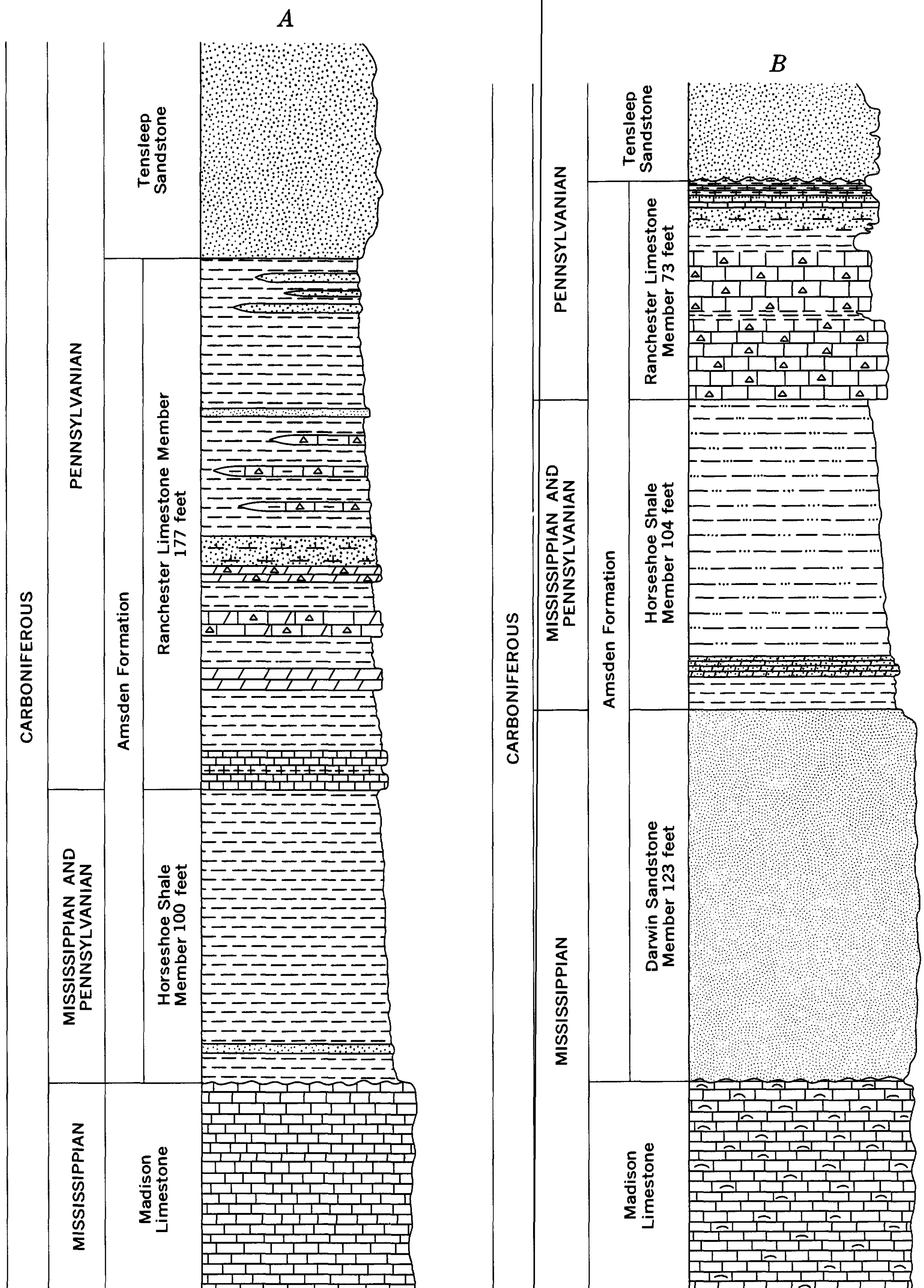

FIGURE 6.—Type and reference sections of the Amsden Formation. *A*, Type section of the Amsden Formation and of the Horseshoe Shale and Ranchester Limestone Members at Amsden Creek, northern Bighorn Mountains, Sheridan County, Wyo. *B*, Reference section for the Amsden Formation and for the Darwin Sandstone, Horseshoe Shale, and Ranchester Limestone Members at Tensleep Canyon, west flank of Bighorn Mountains, Washakie County, Wyo.

A reference section for the Amsden Formation is also proposed. This section is near the lower end of Tensleep Canyon, near Tensleep, about half a mile upstream from the Wigwam Trout Rearing Station on the north side of U.S. Highway 16. This reference section is more satisfactory than the type section at Amsden Creek for several reasons:

1. All three members of the formation are present and well exposed.
2. Lithology of each member is typical of the Amsden in Wyoming.
3. Contact with the underlying Madison Limestone is marked by regional disconformity.
4. Contact with the overlying Tensleep Sandstone is at a sharp local disconformity.
5. Section is visible from the highway and easily accessible for study.

Graphic sections of the Amsden Formation at Tensleep Canyon and at Amsden Creek are shown in figure 6.

AGE

Controversy regarding the identity and the age of the Amsden Formation has existed for many years. Much of the uncertainty can be traced to changes in nomenclature and to miscorrelations (Branson and Greger, 1918; Branson, 1937, 1939; Branson and Branson, 1941; Wilson, 1962) in which the Amsden Formation was confused with the Madison Limestone or merged with the Tensleep Sandstone. Recent work shows that the Amsden Formation is Pennsylvanian and Late Mississippian (Chester age) in western Wyoming (Shaw and Bell, 1955; W. J. Sando, written commun., 1965).

Fossils allegedly collected from the Amsden Formation since Darton named and described it in 1904 can be divided into two major groups:

1. Those collected from the Madison Limestone which are Meramec in age and, therefore, have no bearing on the age of the Amsden Formation as it was defined by Darton.
2. Fossils actually collected from the Amsden Formation, most of which are Pennsylvanian but some of which have a Mississippian or Mississippian and Pennsylvanian aspect.

In 1954 Burk systematically studied the literature on the Amsden Formation and did additional work in collaboration with C. A. Biggs and others. He stated (p. 4):

> There is no previously described fauna of known age which is comparable to the assemblage of fossils which has gradually been taken from the Amsden. In order to establish the age of the Amsden, it is necessary, therefore, to examine the known ranges of all those forms which have been collected from beds above the Darwin sandstone. All of the Madison fossils, mistakenly assigned to the Amsden, are omitted from consideration, as well as those forms which were identified with hesitation. New species taken from the Amsden are also excluded from this tabulation.

He concluded (p. 5):

> The greatest number of species are Pennsylvanian in age. There are no identifications which would conflict with a Pennsylvanian age for the Amsden, and there is none which supports an exclusively Mississippian age. If all the forms now generically identified, having a range including both the Mississippian and Pennsylvanian, were found to have been taken from the lower part of the Amsden it might suggest a late Mississippian age for this part of the formation, but an examination of all the faunal lists and the present collection shows that there are as many exclusively Pennsylvanian species known from just above the Darwin sandstone as there are genera and species which have a range including both the Mississippian and Pennsylvanian * * *. The faunal evidence pointed out in this paper makes it necessary to abandon the Mississippian age previously accepted for the Amsden, and confirms its Pennsylvanian age.

The fossil collections reviewed and collected by Burk came from the Wind River, Bighorn, Gros Ventre, and Absaroka Mountains. If Burk's conclusions are valid, that part of the Amsden Formation above the Darwin Sandstone Member in these areas is of Pennsylvanian age. Gorman (1962) collected and identified (with the collaboration of M. L. Thompson) fusulinids from the Amsden in the northern part of the Bighorn Mountains; his conclusions agree with Burk's. The work of Shaw and Bell (1955) and W. J. Sando (written commun., 1965) indicates, on the other hand, that the lower part of the Amsden is of Late Mississippian age (Chester) in the Wind River Range and Washakie Mountains and westward.

Fossils from the Amsden Formation at Darwin Peak in the Gros Ventre Mountains have recently been studied by W. J. Sando and J. T. Dutro (written commun., May 1965). The sequence of faunas is similar to that at Cherry Creek. The age significance of the Cherry Creek section is probably valid for the entire Wind River Range–Gros Ventre Mountains area. Hence, it seems that the Darwin Sandstone Member is of Late (Chester) Mississippian age; the Horseshoe Shale Member is of Late (Chester) Mississippian and Early (Morrow) Pennsylvanian age; the Ranchester Limestone Member is of Early and Middle (Morrow and Atoka) Pennsylvanian age.

NOMENCLATURE AND THE AMSDEN PROBLEM

As stated earlier, Darton (1904, p. 396–397) recognized two major lithologic units in the Pennsylvanian System of central Wyoming. He applied the name Tensleep to an upper massive sandstone unit and the name Amsden to a lower sequence of limestone, red shale, and basal sandstone that lies on the Madison Limestone. In

1906 (p. 31–34) Darton more explicitly described the Amsden. In 1918 (p. 422–423) Blackwelder designated the basal sandstone unit described by Darton as the Darwin Sandstone Member of the Amsden Formation.

Also in 1918, however, E. B. Branson and Greger (p. 310–311) discussed strata which they called Amsden at Bull Lake Canyon, where the Amsden and the Madison are well exposed in the canyon walls, and at Cherry Creek, near the Canyon of the Little Popo Agie River (sec. 19, T. 31 N., R. 99 W.) southwest of Lander, where poorly exposed red sandy siltstone and shale of the Horseshoe Shale Member of the Amsden Formation lie on the Madison Limestone. Branson and Greger's text (p. 310–311) indicates that part of the Cherry Creek fauna was apparently collected from a ledge in the Horseshoe Shale Member and part from purple limestone float. The Bull Lake fauna was collected from the upper 76 feet of the Madison Limestone, which they called Amsden. The Darwin Sandstone Member at the base of the Amsden overlying this zone in the Madison is referred to by them as the Tensleep Sandstone. These authors, therefore, correlated the middle red shale (Horseshoe) of the Amsden at Cherry Creek (where the Darwin Member is absent) with the upper part of the Madison Limestone at Bull Lake Canyon despite gross differences in lithology and stratigraphic position. This miscorrelation and the confusion which it engendered are responsible for much of the contradiction in the literature.

In a 1937 paper discussing the Amsden Formation and the Madison Limestone at Bull Lake Canyon, C. C. Branson (p. 650–652) also failed to recognize the presence of Blackwelder's Darwin Sandstone Member of the Amsden Formation, and followed E. B. Branson and Greger's terminology in that he correlated the Darwin with the Tensleep and extended the name Amsden down into the Madison Limestone. C. C. Branson called (1937, section, p. 651) Darton's Amsden Formation the "Upper Amsden" and the uppermost 18 feet of the Madison Limestone the "Lower Amsden." Below Branson's "Lower Amsden" is 43 feet of Madison Limestone with a reported Meramec fauna and 2 to 11 feet of solution-breccia limestone which he named the Sacajawea Formation. In 1939 (p. 1202) C. C. Branson expressed dissatisfaction with Darton's dual Pennsylvanian designations—Tensleep Sandstone and Amsden Formation—and proposed that the name Tensleep be redefined to include all of Darton's Amsden Formation and that part of the Madison Limestone which Branson termed "Lower Amsden" in 1937. Thus, by Branson's definition the revised Tensleep Formation rests on his Sacajawea Formation. In 1941, E. B. Branson and C. C. Branson (p. 131–132) used the same nomenclature as C. C. Branson had in 1939 and proposed that the name Amsden be abandoned.

The confusion has recently been intensified by Wilson (1962). For example, in Wilson's figures 7 and 8 the name Sacajawea (a zone in the upper part of the Madison Limestone) is applied to the Darwin Sandstone Member, and concentric age patterns show that the Ranchester Limestone Member of the Amsden Formation ranges in age from Morrow to Virgil and grades laterally into the Darwin and Tensleep. Todd (1964) discussed petrology but took his stratigraphy from Wilson.

Because the Amsden Formation is a simple tripartite sedimentary unit with only modest regional facies variation over a wide area, the nomenclature proposed by Darton fits well with observed facts nearly everywhere in central and western Wyoming and has priority over the later proposals by Branson and Branson (1941).

DARWIN SANDSTONE MEMBER

Lithology and thickness.—The Darwin Sandstone Member is a gray, white, or cream-to-salmon sandstone; locally it is brick red or has brick-red blotches or specks. Its most conspicuous features, aside from color, are crossbedding, a high degree of sorting, and purity of composition (fig. 7). Minute quantities of arkose were noted by Bishop (1957, table 3) in the DuBois area in the northern Wind River Range of Wyoming, but generally the member is composed almost entirely of fine to medium quartz sand. The cement is silica or, locally, calcite (Agatston, 1954, p. 516). A high degree of sorting and a paucity of heavy minerals suggest that the Darwin was derived from preexisting sandstones (Bishop, 1957).

The thickness of the Darwin ranges from 0 to 145 feet and changes abruptly from place to place (pl. 2(*A*)).

Age.—No fossils are known from the Darwin Sandstone Member, but its age is late Chester in the Wind River Range. At Sinks Canyon, near Lander, the Darwin is overlain by the Horseshoe Shale Member; but 10 miles southeast, at Cherry Creek, the Darwin is absent owing to pinchout or gradation into the lower part of the Horseshoe, which there lies directly on the Madison Limestone. (See p. G13.)

Depositional history.—As geosynclical marine waters transgressed eastward onto the Wyoming shelf in late Chester time, the Wyoming River system became a shallow estuary or bay. Sand from an exotic northern or eastern source was deposited in the bay in earliest Darwin time and continued to accumulate as the Madison topography was inundated. Because relief on the Madison surface averaged about 150 feet over thousands of square miles, relatively small rise of sea level could have produced widespread inundation. Alternating pe-

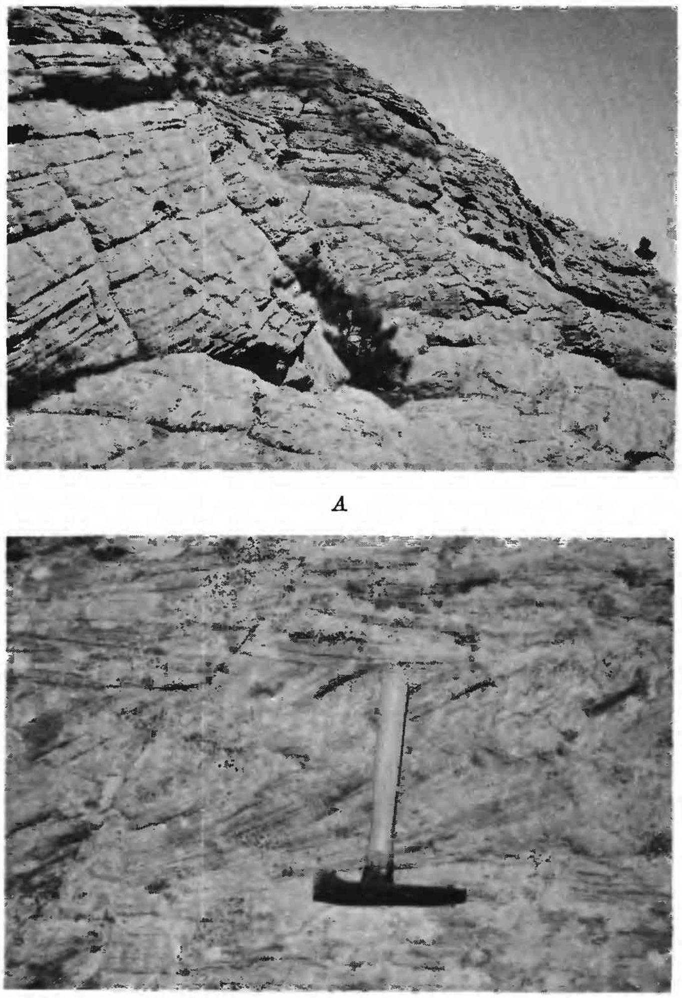

FIGURE 7.—Crossbedding in the Darwin Sandstone Member, Tensleep Canyon, Bighorn Mountains, Wyo. *A*, large-scale crossbedding; *B*, small-scale crossbedding. Large-scale crossbedding is more common.

riods of emergence and submergence, possibly caused by eustatic changes, may have allowed wind and waves to build a complex network of crossbedded dunes, beaches, and bars.

The extent and thickness of the Darwin in the Bighorn Mountains area deserve special comment. The presence of an unusually irregular featheredge of the Darwin on the west flank of the Bighorn Mountains (pl. 2(*A*)) is established by the control net in the area; the presence of an unusually thick local patch of the Darwin in central Johnson County near Buffalo needs explanation. Apparently, in Darwin time the Bighorn Mountains area was uplifted as an asymmetrical arch or fault block with a minimum displacement of about 150 feet. The Wyoming River, flowing south through Johnson County and carrying sand from an exotic source, apparently was antecedent to the arch or block and was ponded for a time by this tectonic event. In the resulting lake, the Darwin accumulated to a maximum thickness of about 150 feet. Another local patch in central Sheridan County may have had a similar origin. On the west side of this arch or block near Mayoworth, the irregular limit of the Darwin may have been accentuated by erosion of the Darwin shortly after deposition. Support for the assumed existence of a fault or sharp flexure in the Bighorn Mountains area near Mayoworth is provided by the existence later in Morrow time of the Casper peninsula of the Front Range uplift (pl. 2(*B*)), whose trend generally paralleled the Mayoworth fault or flexure. Maughan (1967) noted the existence in Permian time of a tectonic alinement extending from the northeast flank of the Laramie Mountains into the Bighorn Mountains, and this may possibly have been a rejuvenation and southward extension of the Mayoworth alinement.

HORSESHOE SHALE MEMBER

Lithology and thickness.—The lithologic unit above the Darwin Sandstone Member is typically red shale and siltstone. It is widespread in northwestern Wyoming (pl. 2(*B*)), and its striking color is a useful criterion for identifying the Amsden Formation in outcrop and in well cuttings. Where the Darwin Sandstone Member is absent, the Horseshoe Shale Member rests directly on the disconformity at the top of the Madison Limestone. Beds of sandstone, limestone, and dolomite locally compose the bulk of the member as in the Cities Service Sprecher 1 well, sec. 22, T. 36 N., R. 82 W., Natrona County, and in Dinwoody and Bull Lake Canyons, but red shale predominates nearly everywhere else. Mudstone, claystone, shale, siltstone, and thin sandstone and carbonate beds are common auxiliary constituents. The shale has paper-thin to massive structure, and thin and regular bedding, and commonly has chunky or blocky shale. The color is usually bright, commonly ranging from purple or maroon to brick red; locally, yellowish and light-pinkish-gray shale is present. At Dinwoody and Bull Lake Canyons the shale is gray green and is copiously interbedded with thin beds of dolomite and sandstone.

A distinctive feature of the Horseshoe Member, described in detail by Mundt (1955, p. 68–73), is red to black ferruginous pisolites in the middle of the unit. This "buckshot pellet" zone is widespread in Wyoming and is identifiable on surface exposures in the southern part of the Laramie Mountains, on both sides of the Bighorn Mountains, on the east side of the Wind River range, and elsewhere in the intervening area. Individual pellets are typically about 10 mm in diameter, deep red to black, spherical to ellipsoidal, and in some areas devoid of discernible internal structure. J. F. Murphy (oral commun., 1964) reported that in the Dinwoody–Bull Lake Canyons area well-developed concentric structure is common. A trace of the ferruginous pisolitic zone has been identified in a well at Worland dome, T. 48 N., R. 92 W., Washakie County, on the east side of the Bighorn Basin (Agatston, 1954, p. 518).

The isopach map of the Horseshoe Member of the Amsden (pl. 2(*B*)) contrasts markedly with that of the Darwin Member. The Horseshoe is a nearly tabular layer, averaging 75 feet in thickness, that was deposited across a relatively flat surface. Locally the thickness exceeds 100 feet; on the margins of the area, 150 feet. The Horseshoe is not so extensive areally as the Darwin. (See pl. 2(*B*), northern Natrona and southern Johnson Counties.)

Age.—A poor exposure at Cherry Creek was visited by Shaw and Bell (1955), who collected fossils from two ledges in the Horseshoe Shale Member. Here the Madison Limestone forms a prominent ledge; the Darwin Sandstone Member is absent. Directly above the Madison a few tens of feet of red beds are discernible in the hillside. Forty-seven feet above the base of the Amsden is a sandy limestone 1 foot thick from which Shaw and Bell collected a shell fauna to which they assigned a Chester age. They also reported the presence of a calcareous silty sandy zone 18 feet above the sandy limestone. From this sandy zone they collected a brachiopod fauna to which they assigned a Pennsylvanian (Morrow or Atoka) age, partly on the basis of evolutionary changes. Shaw and Bell's faunal lists were reviewed by J. T. Dutro, Jr. (oral commun., 1963), who would also ascribe a late Chester date to the forms listed from the lower of the two beds and a transitional Mississippian and Pennsylvanian age to the fauna listed from the upper one.

The fossils listed by Shaw and Bell (1955, p. 334) from the lower of the two beds are as follows: *Composita trinuclea; Composita* sp. indet.; *Eumetria verneuiliana; Eumetria* sp. indet.; *Griffithides moorei; Linoproductus croneisi; ?Myalina sanctiludovici;* "*Orthotetes*" sp.; *?Palaeoneilo amsdenensis; Productus phillipsi?;* "*Pustula genevievensis*"; *Spirifer welleri; spirifer* sp. indet.; "*Schizophoria swallovi*"; "*Spiriferina*" *browni;* and *Torynifer* cf. *T. setigera.*

The fossils listed from the upper bed are as follows: *Composita trinuclea; Composita* sp.; *Linoproductus* sp. indet.; *Spirifer opimus;* Bellerophontid gastropod; Tetracoral; *Composita ovata; Composita subtilita; Composita* sp. indet.; *Eumetria* sp. indet.; *Spirifer* sp. indet.; *Wellerella* sp. indet.; *Dictyoclostus* sp. indet.; *Eumetria sulcata;* and *Wellerella osagensis?*

W. J. Sando (written commun., 1965) recently collected, from beds above the Darwin in the Washakie Mountains, fossils which he considered to be of Late Mississippian age. Hence, the lower part of the Horseshoe Shale Member in this area seems to be of Chester age, and the upper part, Morrow.

Environment and provenance.—The nearly constant thickness and lithology of the Horseshoe Shale Member in the Bighorn–Wind River region suggests that in post-Darwin Morrow time this area was a stable shelf or platform. Because the area was bounded on the west by the Cordilleran geosyncline, on the south by the tectonically active Ancestral Rocky Mountains and associated troughs, and on the east by a shallow basin in northeastern Wyoming, the term "platform" seems appropriate. For this reason the term "Bighorn–Wind River platform" is used in this report as a convenient designation.

The most obvious source for the red material would seem to have been the area of exposed Precambrian rocks in the Ancestral Rocky Mountains in southeastern Wyoming. If this were the source, however, strata of the Horseshoe Member should become markedly coarser grained in that direction. Instead, the rocks of equivalent age near the Front Range uplift (Casper Formation) are mostly sandstone and limestone (pl. 2(*B*)). The coarse arkosic conglomerate typical of rocks younger than the Horseshoe in this area is absent.

Because Pennsylvanian seas covered only parts of Montana and did not extend very far into south-central Canada (Sloss and others, 1960, p. 34), a wide expanse of Mississippian and older limestone was exposed to weathering and solution in Chester and early Morrow time. A red residual soil may have formed on this limestone terrane and then been transported in Chester and Morrow time southward into Wyoming and deposited on the Bighorn–Wind River platform. If this weathering and transportation occurred, red soils may also have formed on the weathered surface of the Madison farther south in Wyoming and should now be in place at the base of the Darwin Sandstone Member; but no evidence of this has been found.

The thin regular-bedded aspect of the Horseshoe Member beds in many areas, the lack of ripple markings, and the local presence of carbonate beds indicate that the member was deposited in quiet water of moderate depth under unusually stable tectonic conditions.

If the source of both the Darwin and the Horseshoe sediments was exotic and distant, an event in the provenance area could have been responsible for the change of material being carried into the region. That the origin of red color in sediments is not entirely understood further complicates the problem. At least it can be stated

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that at some time the red beds of the Amsden had access to abundant oxygen. Perhaps the material was oxidized in the source region, or possibly the material was in a reduced state at the source and oxidized during transportation. The color may have been derived during the process of deposition by shallow inundation alternating with exposure to the atmosphere on a broad depositional shelf. Some combination of all three processes must also be considered. Local areas of green shale must have had a different history.

RANCHESTER LIMESTONE MEMBER

Lithology and thickness.—The Ranchester Limestone Member of the Amsden Formation is composed predominantly of carbonate rock that is usually gray, tan, pink, or purple, dense or finely crystalline, massive, and cherty. It is characterized by pink to dark-red shale partings or shaly limestone beds that crop out as a series of massive ledges, and by chert that commonly litters the red shale slope of the Horseshoe below (fig. 8). Red pigment from overlying iron-rich shales stains the limestone ledges to give the Ranchester a pink to red tinge in many areas. Locally sandstone is the dominant lithology in the upper part of the member.

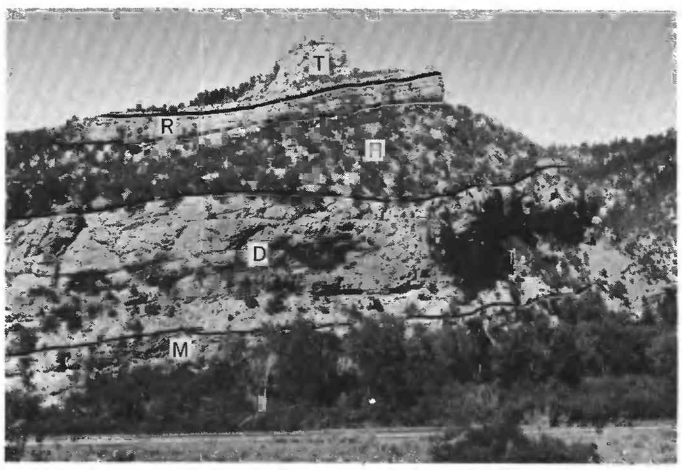

FIGURE 8.—North wall of Tensleep Canyon near trout-rearing station showing the top of the Madison Limestone (M), the Darwin Sandstone (D), Horseshoe Shale (H), and Ranchester Limestone (R) Members of the Amsden Formation and the lower part of the Tensleep Sandstone (T). For comparison see Darton (1906, pl. 16*B*).

The carbonate beds of the Ranchester range in composition from limestone through dolomitic limestone to dolomite. Generally the carbonate beds of the unit are separated by white to gray sandstone, siltstone, and claystone, which commonly grade into argillaceous, silty, or sandy limestone. Thin beds of pink, purple, red, lavender, or light-green shale are also common. Mundt (1955, p. 75) noted that there seems to be no uniform occurrence of dolomite and limestone within this member in Wyoming, but he reported that Nieschmidt (1953) showed 24 subsurface and 2 surface sections in central Montana where an upper dolomitic part overlies limestone.

Chert occurs as irregular nodular masses, as fracture fillings, and as banded beds; it may be red, orange red, white, gray, or tan (Agatston, 1954, p. 519). Bedding in the carbonate strata ranges from thin to massive; shale partings are common; stylolites and local intraformational disconformities are present but not abundant. Intergranular porosity in the dolomite facies, pseudo-oolitic texture, and vugular porosity are discernible locally on the outcrop and, if in suitable association with other factors in the subsurface, may form petroleum or natural-gas reservoirs.

The thickness of the Ranchester Limestone Member generally ranges from 0 to 250 feet (pl. 2(*C*)) and averages about 100 feet. In a belt trending northwest from Casper to the Montana line, the member is less than 100 feet thick; furthermore, isopach patterns of this belt show markedly northwest trends. During deposition of the Ranchester this belt may have been a platform or gently uplifted block related to the fault or flexure southwest of Mayoworth, which was active in Darwin time. The thickness of the Ranchester in the western part of the Bighorn Basin and in the Wind River Basin averages about 150–200 feet; there, a northwest trend is also apparent in the isopach pattern.

Age.—The carbonate beds of the Ranchester Limestone Member have yielded abundant microfossils which have been useful in establishing its age. At Amsden Creek, in a light-gray dense limestone bed 5 feet above the base of the Ranchester, Gorman (1962, p. 25, 28; 1963, p. 69) collected a fusulinia fauna that he identified as *Millerella* sp., *M. inflecta*, *Paramillerella pinguis*, *P. circuli*, *P. ampla?*, *P. advena*, *P.* sp., and *Nankinella*, and to which he assigned a Morrow age. From a comparable horizon along U.S. Highway 14 near Tongue River Canyon (a few miles south of Amsden Creek), Gorman collected *Paramillerella advena* and *Nankinella?*.

A macrofauna was collected by Eliot Blackwelder (Love, 1954) at Darwin Peak from a horizon at the base of the Ranchester. The forms were identified by G. H. Girty as Early Pennsylvanian.

Henbest (1954, p. 50–51) identified a protozoan fauna collected at five localities from the upper part of the Amsden Formation in south-central Montana, just north of the report area. He listed the following forms: *Endothyra* sp., *Bradyina* sp., *Millerella?* sp., *Profusu-*

linella sp., *Climacammina* sp., *Tetrataxis* sp., and *Pseudostaffela* sp. He commented as follows:

The species of *Climacammina*, *Bradyina*, *Endothyra*, and *Tetrataxis* in these collections have not been clearly defined and are not known to be restricted to the Early or Middle Pennsylvanian, but an association in such abundance is common in rocks of Atoka and Des Moines age and rarely found in older and in younger rocks. All those genera probably range from Mississippian to Permian * * *. The Amsden species of *Pseudostaffella* is minute but has regular growth form. The earliest record of this genus is in rocks of Atoka age.

The most characteristic foraminifer in these collections of the Amsden is a highly specialized species classed with question as *Profusulinella*. No species of fusulinids resembling this form have been recorded in rocks known to be older or younger than the Atoka. All of the earliest Atokan relatives of this species are decidely more primitive, but equally complex fusulinids appear before the end of Atoka time * * *.

No evidence of Mississippian age was recognized in these six collections. Atoka, Pennsylvanian, age seems to be rather well substantiated. Nevertheless, the foraminiferal fauna is so peculiar and the knowledge of Late Mississippian and Early Pennsylvanian foraminifers so incomplete that this age determination should not be accepted without reservation. In addition, it must be emphasized again that this conclusion on the age of the Amsden applies only to the parts of the formation represented by these collections.

Love (1954, col. 14) listed a macrofauna from a limestone interbedded with sandstone, which may be uppermost Amsden or lowermost Tensleep. He cited an unpublished manuscript by Eliot Blackwelder as source of the information and indicated that the fossils were collected by C. L. Breger at Dinwoody Lakes, in the northwestern part of the Wind River Range, and identified by G. H. Girty, who considered the age of this assemblage as Atoka.

The available evidence seems to indicate that the lower part of the Ranchester Limestone Member is Morrow and that the remainder is of Atoka age.

Tectonic activity during Ranchester time.—Tongues or lenses of clastic rock in the Ranchester Limestone Member probably derived their material from four source areas: the Pathfinder uplift, the Front Range uplift, an apparent source on the site of the Wind River Range, and an apparent source in Montana, north of the report area. Of these source areas, the Pathfinder is the most completely documented and had greatest areal extent and elevation in Atoka time (Mallory, 1963).

In 30 wells and surface sections on the site of the Pathfinder uplift, the Ranchester Member is missing; an additional 35 control points in the surrounding area show that the Ranchester thickens away from the uplift nearly everywhere at a uniform rate of 10 feet per mile (fig. 9, pl. 2(*C*)). In southern Albany County the rate of thickening of rocks of equivalent age increases to 65 feet per mile south of Laramie.

The areal geology indicates that the Pathfinder uplift consisted of four distinct parts in Atoka time (fig. 9; Mallory, 1963):

1. A northeastern segment where Madison Limestone of Mississippian age formed the surface rock.
2. A central belt which bore a cover of carbonate rock, shale, and sandstone of Morrow age (the lower part of Casper Formation) (pl. 2(*B*), fig. 9).
3. A southern extension where igneous and metamorphic rocks of Precambrian age were exposed.
4. A western extension where Madison Limestone probably formed all or much of the surface.

At present, Tertiary rocks lie on Precambrian over much of the western extension. However, the fact that Pennsylvanian strata rest on the Madison Limestone in many places at the edge of the Sweetwater uplift suggests that Mississippian strata extended partly or entirely over the western part of the Pathfinder uplift at the close of Atoka time and were removed by erosion following the Laramide deformation. Figure 9, therefore, shows Madison Limestone on the western extension of the Pathfinder uplift; local inliers of older Paleozoic and basement rocks may have been present in stream valleys.

The composition and location of the tongues or aprons of clastic rock marginal to the Pathfinder uplift are related to both the areal geologic pattern of the uplift in Atoka time and the degree of tectonic activity in each of the four divisions. Moderate uplift of the western extension caused sandstone and shale of the Horseshoe Member to be removed and redeposited as tongues of clastic material in the Ranchester sea. Strong uplift of the southern extension, in Albany County, allowed igneous and metamorphic rocks of Precambrian age to be actively weathered, eroded, and redeposited on the southern shores of the uplift as arkose of the Fountain Formation. The northeastern segment was moderately uplifted, causing beds of Morrow age to be removed and redeposited in the Atoka sea, but uplift was not adequate to cause the Madison to be stripped away. The central belt must have been a lowland nearly awash in the sea, because clastic strata of the lower part of the Casper were not removed and adjacent clear marine waters were therefore uncontaminated by mud and sand.

Erosion of the Front Range uplift contributed abundant arkosic gravel and sand to the trough in the Laramie basin area. This material mingled with similar material eroded from the south end of the Pathfinder uplift. Arkosic conglomerate of the Fountain Formation of Atoka age is present as far west as the vicinity of Rawlins in the Sinclair Oil and Refining Unit 1 (sec. 28, T. 21 N., R. 86 W.) (pl. 1, *B–B′*; pl. 2(*C*)). In

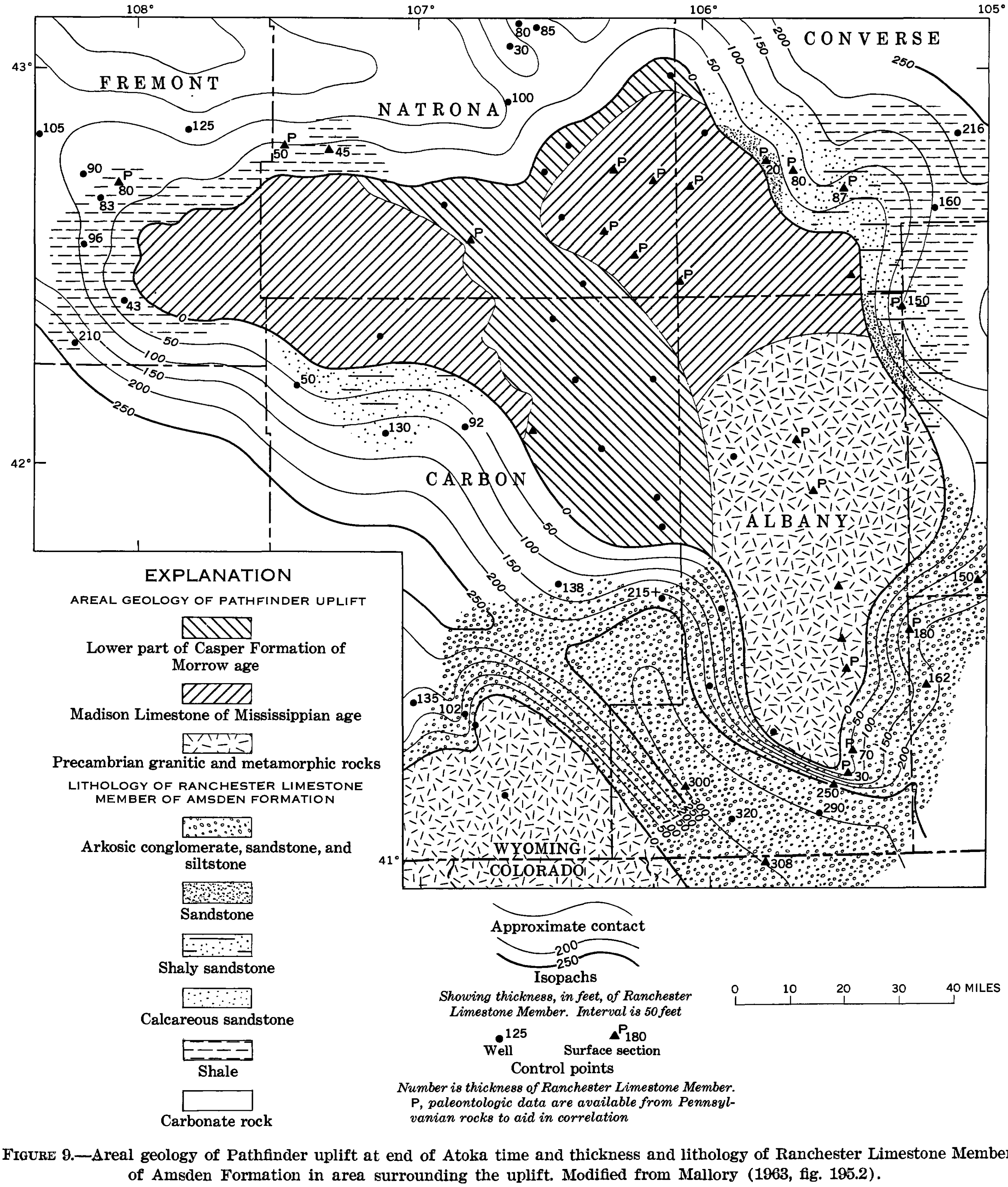

FIGURE 9.—Areal geology of Pathfinder uplift at end of Atoka time and thickness and lithology of Ranchester Limestone Member of Amsden Formation in area surrounding the uplift. Modified from Mallory (1963, fig. 195.2).

southwestern Carbon and southern Sweetwater Counties, scattered control suggests that a belt of sandy calcareous shale fringes the north and west margins of the Front Range uplift. Because coarse material is scarce, uplift in this area presumably was less intense than in the vicinity of Laramie.

The presence of rocks of Atoka age along the south edge of Sweetwater County is questionable. Verville and Momper (1960) reported only 67 feet of strata of Atoka age in the Mountain Fuel Unit 1 well in sec. 21, T. 16 N., R. 104 W. Although some workers (Thompson, 1945, p. 26–27; Baker and others, 1949, p. 1181–1182) cited the possible occurrence of Atoka rocks along the south side of the Uinta Mountains, Sadlick (1955, p. 58) found that strata containing Des Moines fusulinids lie disconformably on strata containing Morrow fusulinids along the north edge of the range. Thus, Atoka rocks are thin or absent along the Colorado-Wyoming boundary, and the Front Range uplift may have extended westward into this region during Atoka time.

Shale, sandstone, and shaly or sandy carbonate rocks in the Ranchester Limestone Member around the Wind River Range (pl. 1, *A–A′*; pl. 2(*C*)) suggest that an island may have existed here in Atoka time, perhaps as a detached segment of the Pathfinder uplift and, hence, the northwesternmost element of the Ancestral Rocky Mountains. If so, the Ancestral Rocky Mountain tectonic trend extended for 1,000 miles in a nearly unbroken chain from the cratonic margin of the Cordilleran miogeosyncline near Jackson Hole southeastward to the cratonic margin of the Ouachita geosyncline near Ardmore in southern Oklahoma.

Tongues of calcareous clastic rock in the northern part of Wyoming (pl. 1, *B–B′*, *C–C′*; pl. 2(*C*)) were apparently derived from a source or sources north of the report area. The materials in these tongues may have been derived from rivers flowing southwest from southern Canada and been deposited as deltas and turbidites in the otherwise clear Atoka seas of Wyoming and southern Montana.

CASPER FORMATION

The Casper Formation, which occurs in the Laramie basin and on the flanks of the Laramie Range in the southeastern part of the State, was named by Darton in 1908 (p. 418–430). He proposed the name for a massive limestone and sandstone sequence which, with the Fountain Formation, composes the Pennsylvanian System in the Laramie Mountains area. These rocks are the southeastward extension of the Amsden and Tensleep Formations but differ enough lithologically to warrant another name (Darton, 1908, p. 418).

Like many Pennsylvanian formations in the Western United States, the Casper Formation differs markedly in lithology from bed to bed and from area to area. Hence, a detailed description of its lithology at one place does not serve as a competent identification at another. In general, however, the Casper is predominantly composed of carbonate rock and sandstone, commonly in massive beds. The color is usually gray, buff, or white, but shades of pink and red are common. The carbonate layers are typically gray, tan, pink, or white, dense to finely crystalline, massive, locally oolitic limestone, dolomitic limestone, or dolomite. Locally, they are sandy, vuggy, and cherty. The chert is red, pink, tan, brown, black, white, or gray. Locally, carbonate beds are purple to lavender, dense to lithographic, and thin bedded.

The sandstone layers are red, pink, white, buff, or gray, commonly crossbedded, friable, and locally quartzitic. The quartz grains range from coarse to fine. A detailed description of the Casper Formation was given by Agatston (1954, p. 536–548).

Crossbedding in the Casper Formation is well exposed in the valley of Sand Creek, southwest of Laramie, in a series of spectacular monuments and pillars. The term "festoon cross-lamination" was introduced by Knight (1929, p. 56; 1953) to describe the primary structures at this locality. Unusually good examples of primary crumpling of sedimentary strata caused by subaqueous gliding are also there (Knight, 1929, p. 74–78).

In the Casper area a red mudstone, locally containing sand and conglomerate and generally about 10 feet thick, is found in wells and at the surface within the upper part of the Casper Formation. This bed, informally named the "red marker," is considered the lowermost unit in the Permian System. The following discussion is quoted from Maughan (1967, p. 132):

> The base of the Permian System in Wyoming is placed at the lower contact of a mudstone known as the red marker, originally recognized in the subsurface of the Lance Creek field in central eastern Wyoming but now known in most of southeastern Wyoming and southwestern South Dakota. This very distinctive unit, composed of red mudstone with minor dolomite and sulfates, is recognized in the subsurface over a very large area. It is also exposed in the Hartville Formation in the Hartville uplift (J. W. Strickland, oral commun., 1958), in the Minnelusa Formation of the southern Black Hills (C. G. Bowles, oral commun., 1959), and somewhat less certainly, in the Casper Formation of the Laramie Range. The red marker does not extend westward into central Wyoming beyond Casper nor northward into northeastern Wyoming, northwestern South Dakota, or beyond.

On the east fork of Wagonhound Creek, Carbon County, Wyo., the red marker forms a prominent bench in the Tensleep Sandstone (fig. 10). There the marker is about 5–20 feet thick and resembles the Fountain

FIGURE 10.—The red marker (bracketed) on east fork of Wagonhound Creek, west of Arlington, T. 19 N., R. 79 W., Carbon County, Wyo. Photograph by E. K. Maughan.

Formation. It is a mixture of red siltstone, sandstone, and conglomerate, is crossbedded, contains cut-and-fill bedding suggestive of fluvial origin, and has numerous thin but prominent lenses of quartz and feldspar pebble conglomerate. The upper surface of the sandstone that underlies the red marker at Wagonhound Creek is highly irregular and contains solution pits.

That part of the Casper above the red marker is well sorted crossbedded buff quartz sandstone. Scattered within this unit are coarse grains of quartz several times larger than those of the matrix.

That part of the Casper Formation that lies below the red marker and is of Pennsylvanian age ranges in thickness from about 100 to 600 feet (pl. 3(*D*)). It is the lateral equivalent of the Tensleep Sandstone, the upper two members of the Amsden Formation, and possibly the upper part of the Darwin Member and is Morrow, Atoka, Des Moines, Missouri, and Virgil in age, although at any one locality rocks of one or more of these ages may be missing (pls. 2(*B*, *C*) and 3(*A*, *B*, *C*); Thomas and others, 1953). Those parts of the Casper that are of Morrow age and nearly all the parts of Atoka age occur only in the subsurface (pls. 1 and 2(*B*, *C*)). Surface sections along the flanks of the Laramie Mountains and adjacent parts of the Laramie basin are Des Moines and younger as indicated by an abundant *Fusulina-Triticites* fauna. Exceptions exist in Deadhead basin and at Farthing on the east flank of the Laramie Mountains where an Atoka fauna has been reported (Pan American Petroleum Co., oral commun., 1960). A correlation of Casper strata into subsurface areas adjacent to the Laramie Mountains was made by comparing subsurface sections in the Laramie basin with surface sections studied by Thomas, Thompson, and Harrison (1953, pl. 9).

FOUNTAIN FORMATION

The name Fountain Formation was given by Cross (1894) to a "series of red sandstones, grits, and conglomerates, a part of the so-called 'Red Beds,' found in typical development on Fountain Creek below Manitou Springs (Colo.)." In its type locality, Cross described the Fountain as "chiefly coarse-grained, crumbling arkose sandstones, in heavy banks showing cross-bedding. They are locally conglomeratic, mottled with gray and various light shades of red, through irregular distribution of coloring matter. Near the base and at intervals throughout the series are very dark red or purplish layers of arenaceous shale in fine-grained sandstone." This description of the Fountain Formation serves well for the entire length of its exposure along the east flank of the Front Range in Colorado, the Laramie Mountains in Wyoming, and for exposures in the Laramie basin. Locally cobbles and boulders of granitic and metamorphic rock and chunks of older Fountain sandstone material are observed in torrentially crossbedded sequences. In the northern part of the Front Range on both flanks of the Laramie Mountains and in the Laramie basin, Maughan and Wilson (1960, p. 34–35) recognized two lithologically distinct parts of the Fountain Formation (fig. 11):

> The upper part of the Fountain differs from the lower part in that it contains many sandstone units with scattered, rounded, coarse grains of quartz and feldspar. Siltstone strata, common in the lower part, are uncommon and only locally present in the upper part. Although the lower part of the Fountain contains some strata of fine-grained sandstone similar in appearance to those of the upper part, none contain scattered coarse grains. The contact between the two parts of the Fountain is placed at the base of the lowest sandstone containing these scattered, well-rounded coarse grains. This sandstone appears to be persistent * * * and is a good horizon marker.

The Fountain Formation is Atoka, Des Moines, Missouri, and Virgil in age. Its areal extent in Wyoming is limited to the southern part of the Laramie basin and the flanks of the southern part of the Laramie Mountains, and it intertongues with the Pennsylvanian part of the Casper Formation to the east, north, and west (pl. 1). A few fusulinids collected from thin limestone and sandstone beds by Maughan and Wilson (1960) and identified by Henbest assisted the author in zoning and correlating the Fountain with the equivalent Casper Formation (fig. 11). According to Maughan and Wilson (1960, fig. 2), the upper part of the Casper, Wolfcamp in age, lies unconformably on the Fountain Formation in the Laramie basin (fig. 11).

MINNELUSA AND HARTVILLE FORMATIONS

The name Minnelusa was applied by Winchell (1875, p. 38) to a sandstone in the Black Hills that is

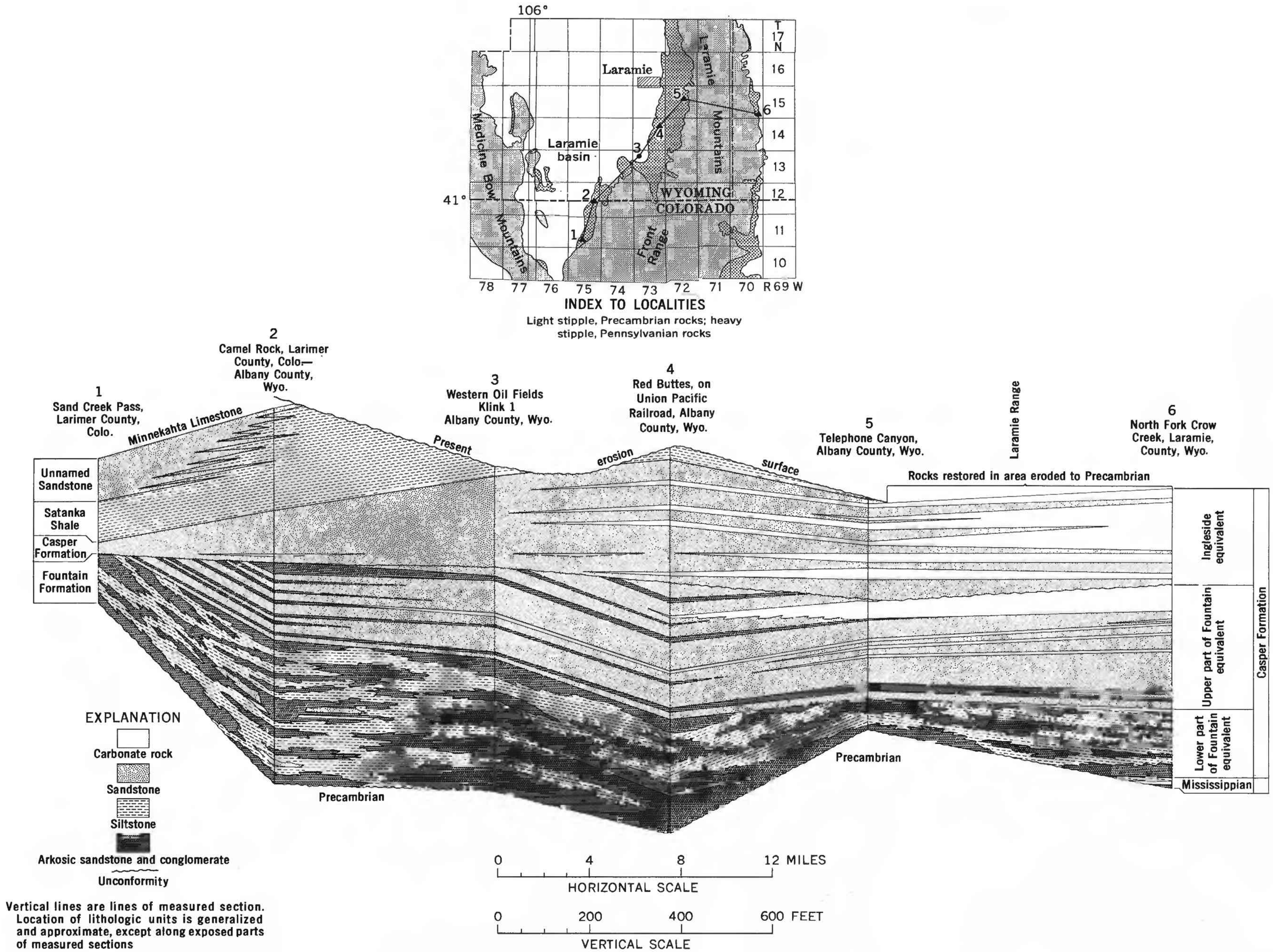

FIGURE 11.—Generalized correlation of Pennsylvanian and Permian rocks across southern part of Laramie basin and Laramie Mountains, Wyo. and Colo. From Maughan and Wilson (1960, fig. 2).

"nearly white, crystalline, subsaccharoidal and coarsely granular when weathered and hard," from which he collected specimens of *Streptorhynchus*, *Athyris*, and *Zaphrentis*. In 1901, Darton (p. 510) used the name to include all sandstones and limestones in the Black Hills region lying between the well-defined limits of the Mississippian Pahasapa Limestone below and the deep-red sandstone and shale of the Permian Opeche Formation above (the entire Pennsylvanian System and the lower part of the Permian System). The Minnelusa is present in the subsurface in the Powder River basin in the northeastern part of Wyoming (not included in this study) and in the Hartville uplift of southeastern Wyoming, where its equivalent is better known by the name Hartville Formation. The Minnelusa Formation in the report area is composed of interbedded limestone, sandstone, and shale. These formations are present only at the east margin of the area.

The Minnelusa and Hartville Formations contain strata of Morrow, Atoka, Des Moines, Missouri, Virgil, and Wolfcamp age, and are the lateral equivalents of the Casper Formation. The thickness of these formations averages about 600 feet (pl. 3(*D*)).

MORGAN FORMATION AND WEBER SANDSTONE

In the Rock Springs uplift, central Sweetwater County, Wyo., only one deep well, the Mountain Fuel Co. Union Pacific Railroad 4, sec. 11, T. 19 N., R. 104 W., penetrates the entire Pennsylvanian System. Formations at depth include the Morgan Formation and the Weber Sandstone. The Morgan consists of cherty fossiliferous carbonate strata with intercalated red shale beds in the lower part, and interbedded sandstone, red shale, and carbonate beds in the upper part. The Weber Sandstone is similar to the Tensleep; it is a massive fine- to medium-grained light-colored crossbedded sandstone with scattered carbonate lenses (American Stratigraphic Co., log CW–1402). The Morgan and Weber are present only in the extreme south-central part of Wyoming. The Morgan is 0 to about 550 feet thick (pls. 2(*B*) and 3(*A*); the Weber is 0 to about 850 feet thick (pl. 3(*B*, *C*)).

The age of the Morgan is Morrow, Atoka, and earliest Des Moines in the Rock Springs Uplift (Verville and Momper, 1960, John Chronic for American Stratigraphic Co., log CW–1402); the Weber was considered of Des Moines, Missouri, Virgil, and Wolfcamp ages by Bissell and Childs (1958, pl. 2).

ROCKS OF MORROW AGE IN THE MINNELUSA, HARTVILLE, CASPER, AND MORGAN FORMATIONS

Rocks of Morrow age (and locally of Chester age) occur in Wyoming as the Horseshoe Shale Member of the Amsden Formation and the lower parts of the Minnelusa, Hartville, Casper, and Morgan Formations (pl. 2(*B*)).

The sandstone east of the Laramie Mountains is part of division 6 of the Hartville Formation or the Fairbank Formation of Condra, Reed, and Scherer (1940). The carbonate strata and the sandy and shaly carbonate strata north of Casper are part of the basal units of the Minnelusa Formation. The sandstone, sandy limestone, and sandy shale in Carbon and Sweetwater Counties are the basal strata of the Casper and Morgan Formations.

Several inferences may be drawn from plate 2(*B*). The northwest arcuate trend of isopachs of the Casper and Morgan Formations in Carbon and Sweetwater Counties reflects the northwest plunge of the terminus of the Front Range uplift, which apparently was in existence by early Morrow time. The northeast trend of isopachs in the Laramie Mountains area, however, is transected by the Casper peninsula of the Front Range uplift, a promontory which extended northward to the city of Casper and contained within its limits nearly all the present-day Laramie Mountains. The discordance between the trend of the Casper Peninsula and the northeast isopach trend nearby leads to the conclusion that Morrow sediments were deposited across the area of the Casper peninsula and removed as a result of uplift in latest Morrow or earliest Atoka time (Mallory, 1963). Abrupt thinning of Morrow strata in the Casper Formation—from 238 feet in the Tidewater Associates Lawn Creek 81–22 well and 301 feet in the J. J. Lynn Burk 1 well (southeastern Natrona and northeastern Carbon Counties) to zero in outcrop sections a few miles away on the west side of the Laramie Mountains—supports this concept. If the Casper peninsula formed before or during Morrow deposition in this area, isopachs should parallel the margins of the peninsula. The greater thickness of Morrow strata in the Laramie basin compared with the thickness on the east side of the Laramie Mountains indicates that greater subsidence occurred in the Laramie basin, or that some upwarping of the east flank of the Laramie Mountains occurred after deposition (perhaps as a corollary of the uplift of the Casper peninsula), or that both subsidence and upwarping occurred.

The predominance of sandstone and sandy limestone in the lower parts of the Casper, Morgan, and Hartville Formations cannot readily be explained. The sand may have been derived from older sediments on the rising Ancestral Front Range uplift, but this assumption is questionable because a wide region in south-central Wyoming and north-central Colorado was periodically emergent in pre-Pennsylvanian time and may or may not have borne a sandstone cover in early Morrow time.

Noteworthy is the absence of arkosic conglomerate of demonstrable Morrow age in the Laramie basin and vicinity.

TENSLEEP SANDSTONE

LITHOLOGY AND THICKNESS

The Tensleep Sandstone (fig. 12) was named by Darton (1904, p. 397). The type locality is in Tensleep Canyon, 7 miles east of Tensleep, Washakie County. The formation is commonly white or cream sandstone, but is tan or pink in a few places. It is fine to medium grained and crossbedded (fig. 13), usually in thick ledges. (See also pl. 16A (facing p. 34) of U.S. Geol. Survey Prof. Paper 51.) The quartz is well sorted, subrounded, and generally frosted. Agatston (1954, p. 522) reported that 59 measurements of crossbedding on the east and west flanks of the Bighorn Mountains indicated no preferred direction of dip, although south and west components were particularly common. Tan, white, and pink finely crystalline locally dense limestone and dolomite beds are commonly interbedded with the massive sandstone ledges of the Tensleep, but usually these carbonate beds compose less than 20 percent of the formation. The carbonate beds are broadly lenticular and are, therefore, of limited use in correlation; laterally they pinch out or grade into sandstone. Throughout much of the area the contact of the Tensleep on the Amsden is sharp, and the two formations are conformable. Locally, where the Ranchester Limestone Member of the Amsden contains many sandstone beds, the contact is obscure. The Tensleep Sandstone grades westward into the Quadrant Quartzite (Scott, 1935, p. 1018).

The Tensleep is best exposed in the Wind River and Bighorn Basins, where it is about 50–350 feet thick.

AGE

Within this broad area abundant evidence indicates that the age of the Tensleep is Des Moines, and locally very latest Atoka (pl. 3(*A*)). Henbest (1954, p. 52) listed seven collections of fusulinids from Fremont and Big Horn Counties, Wyo., and from Big Horn and

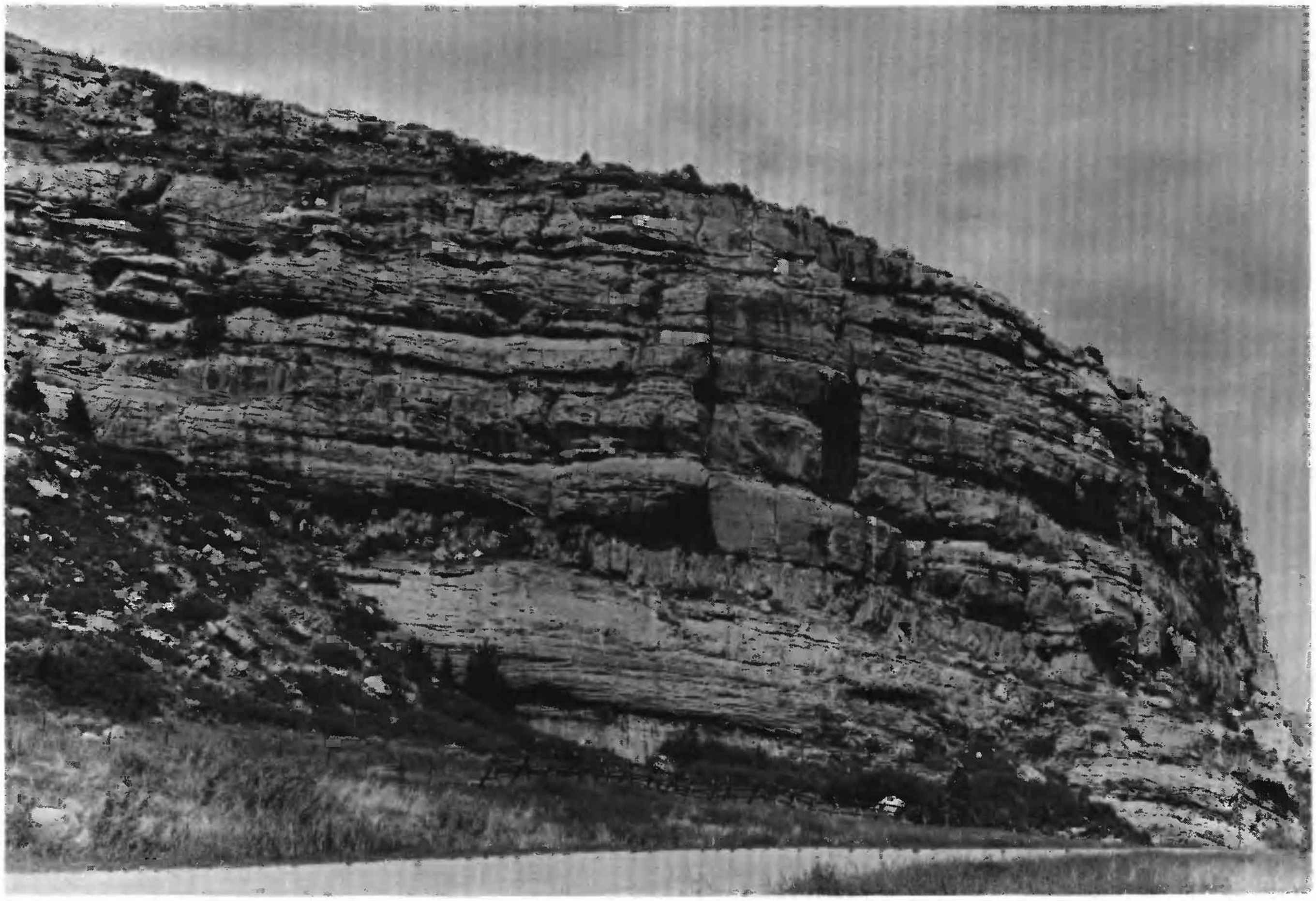

FIGURE 12.—Tensleep Sandstone in Sinks Canyon of Middle Popo Agie River near Lander. Photograph by W. R. Keefer (Keefer and Van Lieu, 1966, fig. 19).

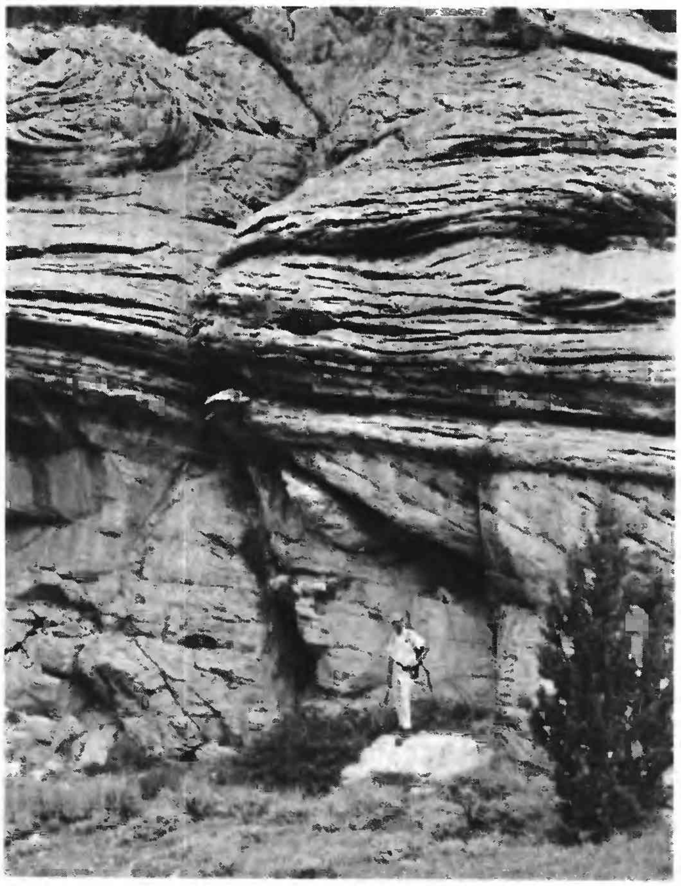

FIGURE 13.—Giant crossbedding in the Tensleep Sandstone, Bull Lake Canyon, Wind River Range.

Carbon Counties, Mont., that indicate that the Tensleep of this region is the age equivalent of the lower half of the Des Moines Series. Forms represented include: *Wedekindellina euthysepta*, *W. excentrica*, *Fusulina distenta*, *F. girtyi*, *F. leei*, *F. tregoensis?*, *F. rockymontana?*, *Bradyina* sp., *Climacammina* sp., *Pseudostaffella* sp., and others. According to Henbest (1954, p. 53), this *Fusulina-Wedekindellina* fauna is one of the most easily recognized and widely distributed assemblages of Pennsylvanian foraminifers. It is typical of the lower half to two-thirds of the Des Moines Series in the midcontinent region and of that age equivalent elsewhere. In 1956 (p. 59–62) Henbest examined 11 additional collections of Tensleep fusulinids from Fremont, Teton, Sublette, Washakie, Sheridan, and Johnson Counties and from Grand Teton National Park. Forms represented, in addition to those just listed, are: *Calcitornella* sp., *Endothyra* sp., *Tetrataxis millsapensis?*, *Globivalvulina* sp., *Fusulinella gephyraea?*, and *Fusulina* or *Fusulinella* sp. An age from very latest Atoka through the early half of the Des Moines is indicated. The specimen of *Fusulinella gephyraea?*, is from U.S. Geological Survey loc. f9791 (Henbest, 1956, p. 61), and is the only specimen of *Fusulinella* of which Henbest was inclined to attempt specific identification. The f9791 collection was taken from a zone of interbedded dolomite, shale, and sandstone at a horizon that is either at or near the contact of the Amsden Formation and the Tensleep Sandstone at Bull Lake Canyon (Murphy and others, 1956). A transitional fauna and lithology with both Atoka and Des Moines aspects at this zone corroborates the ages assigned by Henbest to the upper part of the Amsden (Atoka) and to the Tensleep (Des Moines) in this area.

In the Jackson Hole area in extreme western Wyoming the Tensleep may include beds that are younger than those in the Bighorn Basin. Love (1954, col. 1) indicated that *Triticites* occurred in some part of the formation; Wanless, Belknap, and Foster (1955, p. 35) reported the discovery of a specimen of *Triticites*, but they were not certain as to the horizon represented. At the margin of the Cordilleran miogeosyncline the Tensleep Sandstone may, therefore, range as high as Missouri or Virgil in age.

Similarly, in a narrow belt trending roughly northeast through the center of the State, the Tensleep Sandstone contains strata of Missouri, Virgil, and Wolfcamp ages (fig. 14). Along the east margin of this belt, the Tensleep grades by facies change into the upper parts of the Minnelusa, Hartville, Casper, Morgan, and Weber Formations.

QUADRANT QUARTZITE

LITHOLOGY AND THICKNESS

The Quadrant Quartzite is primarily a well-bedded white to pink fine- to medium-grained quartzite. Locally, where the cement is weak, the rock is friable and readily weathers to sand. At Quadrant Mountain in Yellowstone National Park, the upper part of the Quadrant contains thin beds of calcareous limestone (Scott, 1935, p. 1018). The Quadrant Quartzite is the lateral equivalent of the Tensleep Sandstone.

According to Scott (1935, p. 1013–1014): "The Quadrant formation was named by Iddings and Weed (1899) while working out the geology of the Gallatin Range (1883–93) from its exposure on the southeast corner of Quadrant Mountain in * * * Yellowstone National Park." At Quadrant Mountain the Quadrant Quartzite is 243 feet thick.

AGE

At Quadrant Mountain, Thompson and Scott (1941, p. 350–351) reported a *Wedekindellina excentrica–W. euthysepta?–Fusulina* sp. fauna. From this evidence they concluded that the age was clearly Des Moines although they referred to the formation as "Lower Pennsylvanian" in the title of their paper.

ROCKS OF DES MOINES, MISSOURI, AND VIRGIL AGE

Strata of Des Moines, Missouri and Virgil age also occur in the Minnelusa, Hartville, Casper, Fountain, Morgan, and Weber Formations. Plate 3(*A*, *B*, *C*) shows the extent, thickness, and lithology of strata in the listed formations that are of Des Moines, Missouri, and Virgil ages, respectively.

DES MOINES ROCKS

Rocks of Des Moines age are present everywhere in the area except on the Pathfinder and Front Range uplifts (pl. 3(*A*)). The rocks of Des Moines age are absent at the margins of these uplifts and are at least 350 feet thick in the Wind River Basin and more than 600 feet thick in Sweetwater County. In the southeast quarter of the State the thickness was controlled by the configuration of the adjacent uplifts; the Pathfinder uplift had diminished appreciably in size since Atoka time although it extended a short distance farther north.

In Platte, Albany, and Carbon Counties, the rectangularity of the isopach pattern in northeast and northwest directions is apparent. The northeastern trends are similar to the Morrow trends in the area; the northwestern ones are probably related to the dominant northwestern alinement of the Front Range uplift throughout Pennsylvanian time. The resultant rectangular pattern suggests that block faulting was a controlling tectonic mechanism.

In northwestern Wyoming the Des Moines isopachs trend northeast in contrast with the equally marked northwest trend of Atoka isopachs. The Des Moines trends are unusual in that the linear areas of thin strata are wide and that linear "thicks" are exceedingly narrow. Inasmuch as strata of late Early Permian age in northwestern Wyoming rest on strata of Middle Pennsylvanian (Des Moines) age, the existence of a hiatus at this horizon suggests that simple valley cutting was responsible for the abnormal isopach pattern. Yet valley cutting cannot be the reason because the long narrow trends which superficially resemble valleys are areas of thick Des Moines strata. Valleys eroded into the Tensleep Sandstone would be "thins." Perhaps broad, gently arched northeast-trending anticlines were active during or immediately after Des Moines deposition, and the resultant gentle emergence caused unconsolidated sand to be washed or blown from the crests of tectonic-topographic high areas into adjacent troughs.

Lithologic associations of Des Moines strata are uncomplicated. Because the Quadrant Quartzite and the Tensleep Sandstone contain most of the strata of Des Moines age, plate 3(*A*) shows mainly sandstone. Nearly all northwestern Wyoming was probably a broad platform sloping gently southwest. Its southeast terminus was the Pathfinder uplift which was flanked on the north and east by sandstone that grades into limestone in the Casper and Hartville Formations. A tongue of sandy carbonate rock (in north-central Carbon County) grades southwestward into the lower part of the Morgan Formation, a widespread limestone in the Eagle basin of northwestern Colorado. In southern Albany County calcareous sandstone and arkose make up the Casper and Fountain Formations. A marked decrease in the area of arkose deposition from that in Atoka time implies that the north end of the Front Range uplift was less active in Des Moines time and supplied a smaller quantity of coarse detritus. A small tongue of calcareous and shaly sandstone in the Jackson Hole area in Teton County is an extension of geosynclinal lithologies farther west.

On the platform the Des Moines sea may have been so shallow that the depositional interface lay continually in the zone of wave action. Intermittent emergence and submergence of the platform (related to cyclothems in the Mississippi Valley?) would have allowed wind and waves to continually re-sort the sand grains and arrange them into crossbedded dunes and bars. The thin limestone beds in the Tensleep, Quadrant, and Weber Formations may be records of either deeper-than-usual local subsidences for short periods or temporary quiet-water conditions without influxes of sand.

MISSOURI ROCKS

Strata of Missouri age (pl. 3(*B*)) are absent from all but the easternmost part of the Bighorn and Wind River Basins and are probably absent from much of the Green River basin. The cause is probably lack of deposition, but some postdepositional marginal beveling may have occurred. It seems reasonable that the Bighorn–Wind River platform progressed from periods of shallow submergence alternating with periods of emergence in Des Moines time to complete emergence in later Pennsylvanian time. The position of the present west limit of Missouri strata, however, is probably the result of erosional beveling, the latest episode of which probably occurred in post-Virgil time. This conclusion is supported by the parallelism of the Missouri and Virgil western limits as suggested by the available surface and subsurface control (fig. 14). Critical evidence in locating the western limits of the Missouri, Virgil, and Wolfcamp rocks in northern Wyoming was provided by Verville (1957), who reported the occurrence of *Schwagerina* and *Triticites* of early Wolfcamp age in beds he assigned to the uppermost part of the Tensleep Sandstone at Mayoworth.

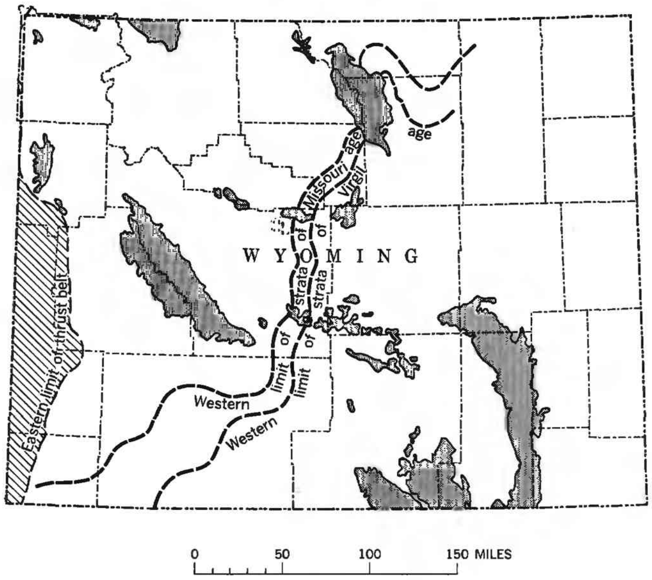

FIGURE 14.—Western limits of Missouri and Virgil rocks in central Wyoming. Data from which these lines are drawn are sparse but suggest that the parallelism of the two lines results from post-Virgil pre-Wolfcamp beveling. Shaded areas indicate Precambrian outcrops in present major mountain ranges.

The Missouri rocks, averaging about 100 feet in thickness, are thinner than the Des Moines. They range from 0 to 200 feet in thickness in the Laramie area and reach a maximum of 250 feet in Sweetwater County. At the east margin of the Bighorn–Wind River platform, a broad belt in Johnson, Natrona, and Carbon Counties was tectonically transitional from a platform margin to a marine shelf in eastern Wyoming, where the rate of subsidence moderately increased eastward. The thickness of Missouri rocks in this belt ranges from 50 to 150 feet. Although isopachs in the transition belt are generally sinuous, isopachs are amoeboid in the vicinity of the Pathfinder uplift, which was limited to a small area at the north tip of the Laramie Mountains.

Perhaps in later Des Moines or early Missouri time the uplift gently subsided. However, the rectangular isopach pattern in Albany County (pl. 3(*B*)) suggests an alternate hypothesis—that foundering of the Pathfinder uplift took place by progressive northward block faulting. In Missouri time a tongue of carbonate strata more than 150 feet thick in southeastern Natrona County occupied the site of the northern part of the Pathfinder uplift of Des Moines time. The limited extent of arkose deposition in Albany County reflects the progressively diminishing uplift of the north end of the Front Range uplift after Atoka time.

The lithologic patterns in the Missouri rocks are generally similar to those of the Des Moines because sandstone is present on the Bighorn–Wind River platform (but only its extreme east margin) and grades eastward into carbonate rock in a short distance along a north-trending belt.

The sinuous pattern of the facies transition zone is most marked in Natrona and Carbon Counties, where the long narrow tongue of shelf carbonate rocks isolates the residual Pathfinder uplift from the Bighorn–Wind River platform sandstone province. After allowance for minor local variations, the coincidence of the narrow quartz-to-carbonate facies transition belt with the tectonic transition from the Bighorn–Wind River platform to a shallow basin in eastern Wyoming is noteworthy. The coincidence shows that sand, probably derived from the Des Moines Tensleep of the Bighorn–Wind River platform, was being carried eastward into the sea, where it was transported laterally by longshore currents. At the same time, nearly pure carbonate was deposited a short distance offshore in eastern Wyoming. Control on the southwest flank of the Pathfinder uplift, though meager, suggests the presence of local sandstone bodies surrounded by calcareous sandstone. Their existence offshore from points of land projecting southwest and south from the Pathfinder uplift in the suspected presence of strong longshore currents suggests that these sands are spits similar in magnitude to those at Cape Cod, Mass. A liberal interpretation was used in indicating the spits on plate 3(*B*). The sand was presumably swept southward around the east and west flanks of the Pathfinder uplift by longshore currents and redeposited as local sand bodies within sandy limestone (Casper Formation). The interpretation regarding southward movement of currents at that time agrees with the conclusions of Opdyke and Runcorn (1960, fig. 1, p. 961), who studied crossbedding in the Tensleep and Casper Formations.

In the southernmost part of the Laramie basin, small volumes of arkose derived from the Front Range uplift were deposited as tongues in the Casper Formation. The carbonate rock in the Campbell-Converse-Platte County area in eastern Wyoming is part of the Minnelusa and Hartville Formations. The sandstone in Sweetwater County is an extension of the Weber Sandstone of the Uinta Mountains area.

VIRGIL ROCKS

Conditions in Virgil time were similar to those during the preceding Missouri. The Bighorn–Wind River platform was emergent; the Johnson-Natrona-Carbon-Albany County belt contained the facies transition from sandstone to limestone in northeastern Wyoming; the Pathfinder uplift was almost completely submerged; and the trough in Natrona County persisted but was much reduced in size (pl. 3(*C*)). The west limit of the

Virgil closely parallels the limit of Missouri strata a few miles farther west, partly owing to nondeposition on the platform but probably mainly owing to post-Pennsylvanian beveling. Thickness of the Virgil in the area ranges from 0 to 300 feet near Casper, but averages about 100 feet.

The Virgil isopach pattern differs somewhat from that of the Missouri, however, owing to post-Virgil pre-Wolfcamp warping and erosion in the vicinity of the Laramie Mountains. As a result, rocks of Virgil age are absent in parts of northeastern Natrona County, southeastern Converse County, central western Carbon County, and an irregularly shaped area east of Laramie.

Lithologic relations in the Virgil are also a continuation of those in the Missouri. Quartz sandstone of the Tensleep on the extreme east margin of the Bighorn–Wind River platform grades eastward and southward into carbonate rock of the Minnelusa, Hartville, and Casper Formations. Longshore currents moving southward bifurcated at the remnants of the Pathfinder uplift and deposited sand along the shore, where it mingled with carbonate mud. Thin lenses of arkose were deposited near Red Buttes, south of Laramie. In southeastern Wyoming the red marker was probably deposited during a brief period of emergence at the close of Pennsylvanian time.

UPPER BOUNDARY OF THE PENNSYLVANIAN SYSTEM

The upper boundary of the Pennsylvanian System is readily identifiable nearly everywhere in western and central Wyoming. The contrast in lithology and color between the white well-sorted sandstone of the Tensleep and the greenish-gray or red siltstone, shale, or carbonate of the Phosphoria and Park City Formations is distinctive (fig. 15). Although the Phosphoria and Park City appear to lie in simple conformity on the Tensleep Sandstone at many places in the Bighorn and Wind River Basins, a hiatus is present at the contact. Keefer and Van Lieu (1966) stated, however, that a disconformity of a few inches to several feet is observable in the Wind River Basin. Also, Eliot Blackwelder (unpub. data, 1911) reported a 4-foot-thick basal conglomerate, with an uneven lower surface, at the base of the Phosphoria Formation in Dinwoody Canyon.

The Tensleep in these areas is Des Moines, whereas the Phosphoria and Park City are mostly or entirely Guadalupe and Leonard. In the northwestern part of the Wind River Basin, however, J. D. Love (oral commun., 1962) collected macrofossils from the Grandeur (lowermost) Member of the Park City Formation that are reported to be of Wolfcamp age. The strata from which they were

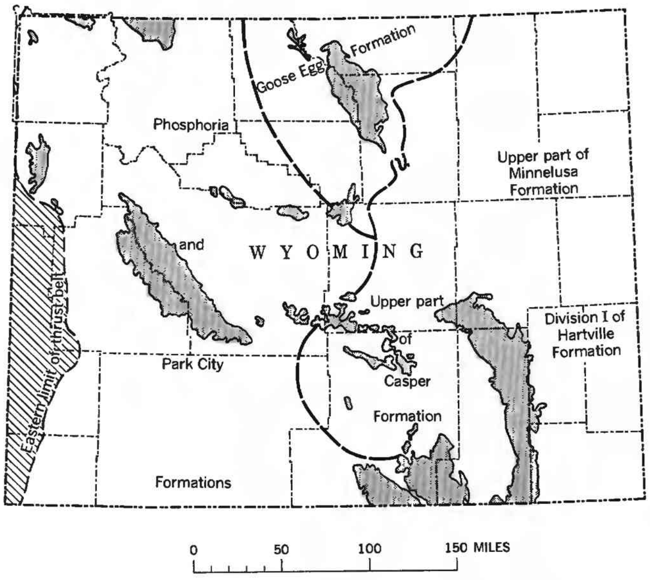

FIGURE 15.—Formations which overlie Pennsylvanian strata in Wyoming. Shaded areas are Precambrian outcrops in present major mountain ranges. After Maughan (1967).

collected may be an outlier or part of a thin tongue extending eastward from the Cordilleran miogeosyncline. The hiatus, therefore, accounts for Missouri, Virgil, and much or all of Wolfcamp time.

In eastern Wyoming, the systemic boundary is within the Casper and Minnelusa Formations and is obscure. Locally, as in the Hartville area, the red marker is helpful in distinguishing between beds of Pennsylvanian and Permian age; but where the marker is absent, paleontological information is necessary. Careful study of the sequence of lithologies is useful, locally, in projecting the boundary from sections where it can be identified from fossils into nearby sections where neither fossils nor the red marker bed is present.

SOURCE OF SAND

The sources of the sand of the Darwin Sandstone Member are unknown. In many parts of the Rocky Mountain and midcontinent regions, the lithologic unit directly overlying rocks that were exposed in Chester and Early Pennsylvanian time is typically red mudstone or detritus of mixed lithology. Commonly, the materials in this unit can be shown to have had local origin. In Chester time, rocks exhibiting a wide variety of lithologies (particularly in southeast Wyoming and Colorado) were exposed to weathering and erosion in the region adjacent to the Darwin depositional trough. The Darwin, however, is a remarkably homogeneous well sorted crossbedded quartz sandstone. The grains are rounded and the heavy-mineral content is low. The purity of composition of the Darwin is in marked contrast, therefore, to the relative impurity of other rock units in the Western United States which occupy a similar stratigraphic position. This circumstance suggests that the Darwin was derived from a widespread older sandstone. Because a large part of North America was emergent in Chester time, long river systems similar to those of the present time probably delivered a variety of materials to the marginal epeiric seas.

An exotic source for the Darwin, therefore, seems reasonable. The isopach map of the Darwin Sandstone Member (pl. 2(*A*)) suggests that the headwaters of the Wyoming River in Chester time lay north or northeast of Wyoming, in Montana, North Dakota, or perhaps as far removed as Saskatchewan, Manitoba, Ontario, and the Hudson Bay area. This whole region was cratonic and contained Paleozoic sandstones older than Pennsylvanian. If one of these sandstones were more extensive in Pennsylvanian time than it is today and was not covered in Pennsylvanian time by strata of intermediate age, it could have served as the source of the sand in the Darwin. Two such sandstones are the basal sandstone formations of the St. Croixan Series of Late Cambrian age and the sandstone formations equivalent to the Chazy Group of Middle Ordovician age.

Cambrian sandstone is present in Saskatchewan and may have once extended farther east (Sloss and others, 1960, p. 1). Ordovician limestone overlaps the Cambrian sandstone in Saskatchewan, however, for at least 250 miles (Macomber, 1960, p. 4); hence, the St. Croixan sandstones could not have been exposed to erosion and redistribution in Chester or in Pennsylvanian time.

Sandstone of Chazy age, much of which is also well rounded and sorted, seems to satisfy the necessary conditions. Kistler (1960, p. 6) showed that strata of Chazy age in Central and Western United States and southwestern Canada occur in widely separated patches: Harding Sandstone in Colorado; Kinnikinic and Swan Peak Quartzites in Idaho; Eureka Quartzite in Utah and Nevada; the Harding equivalent, the Lander Sandstone Member of the Bighorn Dolomite in northern Wyoming; the basal sandstone unit of the Winnipeg Formation in Manitoba, Saskatchewan, Montana, and North Dakota; the quartzite unit of the Wonah Formation in the southern part of the Alberta-British Columbia area; and a sandstone in extreme northeastern Manitoba on the shore of Hudson Bay (Kistler, 1960, p. 6; Baillie, 1952, table 2). Neither Kistler nor Baillie identified this sandstone by name; Kistler showed its areal distribution, and Baillie tabulated an unnamed sandstone in the Hudson Bay area as equivalent to the Winnipeg Formation.

In many of these areas, isopachs abut the limit of the patch, indicating that the present limit is the result of erosional beveling. Possibly, then, most or all of the isolated patches in North America were originally part of a continuous sedimentary unit. Isopach maps of the Silurian, Devonian, and Mississippian Systems in southern Canada (Sloss and others, 1960, p. 12, 14, 23) suggest that the present limit of these systems is not far, regionally, from the original limit. Since these systems do not now extend as far as Ordovician rocks presumably did originally, a belt of Chazy sandstone some 500 miles wide may have been exposed during Chester time (fig. 16).

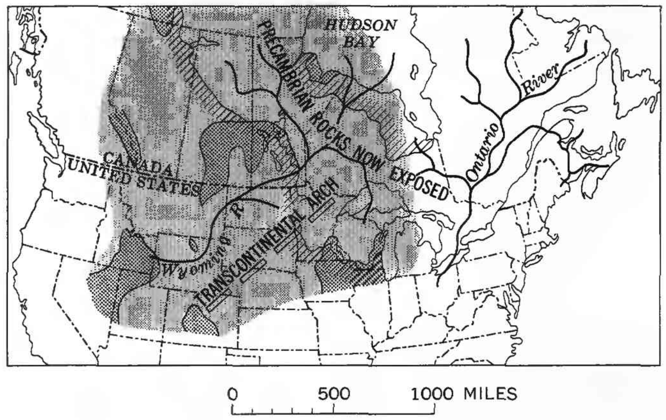

FIGURE 16.—Restored regional drainage patterns for part or all of Carboniferous time in northern United States and southern Canada; present and inferred ancient extent of sandstone of Chazy (Ordovician) age. Stippled areas show present extent of sandstone of Chazy age (after Kistler, 1960); shaded areas show inferred former extent of this sandstone stratum shortly after deposition. Hachured line is present limit of strata younger than Chazy. The broad belt southwest of Hudson Bay where basement rocks of Precambrian age are exposed is the postulated locus of the headwaters of Wyoming River in Chester time. The Ontario River of Pepper, de Witt, and Demarest (1954) of Early Mississippian time is compared with the Wyoming River of Late Mississippian time.

If a gentle doming in the Hudson Bay region occurred in Pennsylvanian time, a major consequent river system with well-developed subsequent tributaries could have acquired sand of Chazy age, carried it uncontaminated across limestone terranes of Silurian, Devonian, and Mississippian age, and deposited it in Wyoming. There marine currents on the Bighorn–Wind River platform transported it seaward.

Support for this hypothesis was provided by the work of Pepper, de Witt, and Demarest (1954), who postulated the existence in Early Mississippian time of the Ontario River of eastern Canada, which provided the material for the Berea Sandstone and associated shales in Ohio and Michigan. Their plate 12 shows the headwaters of the Ontario River to have been in Labrador, the Maritime Provinces, and the region east of Hudson Bay; the delta was in Ohio. The sediment source was preexisting immature sedimentary and crystalline rocks of the craton and the northern part of the Appalachian geosyncline (Pepper and others, 1954, p. 99, 100; Potter and Pryor, 1961, p. 1226). Potter and Pryor (p. 1227) favored a "recycling hypothesis" for many of the sandstones of the upper Mississippi Valley and cited as examples the Chester sandstones of the Illinois basin (p. 1225), whose maturity suggested a contribution from lower Paleozoic sandstones.

The Ontario River is plotted in figure 16 to provide visual comparison with the Wyoming River. Both rivers apparently were of the same order of magnitude (at least 1,000 miles long), and both flowed generally southwest on opposite sides of the Transcontinental arch, a gently positive tectonic trend of major areal proportions active in pre-Pennsylvanian time (Eardley, 1951, pls. 3–5). Their ages, however, are dissimilar. The Ontario River is Early Mississippian according to Pepper, de Witt, and Demarest (1954, p. 13). The Wyoming River is assumed to have supplied the sand for the Darwin Member in Chester time.

Rocks of the Big Snowy Group were being deposited in central Montana in Chester time. Some question exists as to whether the postulated Wyoming River would have been diverted into the Big Snowy marine embayment.

It is not known why sandstone deposition in Wyoming in Darwin time was interrupted in later Morrow and Atoka time and then resumed in Tensleep time, unless stream capture or other unrecorded events in the provenance area were responsible. Perhaps, temporarily in Horseshoe time, the source of red clastics was a laterite from one of many possible limestone provenance areas or was an iron-rich Precambrian terrane. A tributary in the Lake Superior region, for example, may have been supplying iron-rich fine clastics to the Ontario River system in Early Mississippian time which were deposited in Ohio as the red Bedford Shale (Pepper and others, 1954, fig. 60, p. 100). Capture of the upper reaches of this tributary by the Wyoming River system in Chester time may have diverted the same iron-rich material to Wyoming, where it was deposited as the Horseshoe Shale Member of the Amsden with its oolitic iron zone. The problems involved in attempting to resolve the questions which arise in such a postulate are complex and lie largely in the realm of speculation.

During Ranchester time little or no material from an exotic source was introduced into the area.

TABULATION OF CONTROL DATA

SURFACE

No. on pls. 1-3	Location			Locality	Source of data
	T.	R.	Sec.		
			Albany County		
1	12N	75W	23–24	Camel Rock	Maughan and Wilson (1960).
2	14N	72W	4	Gilmore Canyon	Thomas, Thompson, and Harrison (1953).
3	14N	73W	--------	Red Buttes	Maughan and Wilson (1960).
4	14N	77W	17	Sheep Mountain	Mallory (unpub. data, 1939).
5	15N	72W	14–18	Telephone Canyon	Maughan and Wilson (1960).
6	17N	72W	5	Rogers Canyon	Thomas, Thompson, and Harrison (1953).
7	18N	72W	6	Wall Rock Canyon	Do.
8	19N	70W	31	Farthing (Iron Mtn.)	Do.
9	20N	73–72W	--------	Sybille Spring	Hensley (1956).
10	23N	73W	29	Wheatland Reservoir	Thomas, Thompson, and Harrison (1953).
11	24N	74W	11	Garrett	Do.
			Big Horn County		
18	50N	89W	24	Paintrock Creek	Love (written commun., 1956).
19	53N	90W	16	Shell Canyon	Do.
20	56N	93W	6	Cottonwood Creek	Agatston (1954).
			Carbon County		
35	14N	87W	20	Big Sandstone Creek	Ritzma (1951).
36	17N	82W	10	Saratoga area section	Mallory and Maughan (unpub. data, 1960).
37	19N	79W	32	Wagonhound Creek	Bauer (1952).
38	24–25N	82W	2, 35–36	Medicine Bow River	Wilson (1954).
			Converse County		
61	29N	72W	23	La Bonte Creek	Wilson (1954).
62	29N	77W	21	Little Medicine Creek	Thomas, Thompson, and Harrison (1953).
63	32N	72W	33	Bedtick	Love (1954).
64	32N	74W	6	Boxelder Canyon	Do.
65	32N	74W	13	East Fork Little Boxelder Canyon.	Do.
66	32N	77W	26	Deer Creek Canyon	Do.
			Fremont County		
70	1S	2W	33	Trout Creek	Love (1954).
71	1N	3W	28	Pevah Creek	Biggs (1951).
72	2N	4W	2	Bull Lake Canyon	Love (1954).
73	4N	5W	6	Dinwoody Canyon	Do.
74	6N	4W	1	Black Mountain	Love (written commun., 1956).
75	31N	99W	19	Cherry Creek	Shaw and Bell (1955).
76	32N	94W	23	Long Creek Canyon	Love (1954).
77	32N	100W	18	Middle Fork Popo Agie River.	Do.
78	33N	101W	5	North Fork Popo Agie River.	Do.
79	41N	107W	15	Little Warm Spring Creek.	Do.
80	42N	105W	7	Wiggins Fork Canyon	Love (written commun., 1956).
			Hot Springs County		
98	7N	6E	33	Wind River Canyon	Love (written commun., 1956).
99	43N	93W	28	Red Spring	Do.

No. on pls. 1-3	Location T.	Location R.	Location Sec.	Locality	Source of data
				Johnson County	
110	42N	84W	20	Middle Fork Powder River.	Agatston (1954).
111	46N	83W	35-36	Pass Creek	Do.
112	47N	83W	2	Crazy Woman Creek	Do.
113	49-50N	83W		North Fork Crazy Woman Creek and Dry Kelly Creek.	Wilson (1954).
114	52N	84W	25	Rock Creek	Do.
				Lincoln County	
121	38N	116W	28	Martin Creek	Love (written commun., 1956).
122	38N	118W	22	South Indian Creek	Love (1954).
				Natrona County	
123	30N	78W		Bates Creek Reservoir.	Thomas, Thompson, and Harrison (1953).
124	30N	79W		Sheep Creek	Do.
125	30N	83W	17	Northwest Alcova	Love (1954).
126	32N	78W	22	Hat Six Canyon	Do.
127	32N	79W	9	Casper Mountain	Do.
128	33N	87-88W		Garfield Peak combined with Rattlesnake Hills.	Do.
129	33N	89W	23	East Canyon Creek	Do.
130	40N	85W		Buffalo Creek	Agatston (1954).
				Platte County	
162	20N	68W	19	Deadhead basin	Thomas, Thompson, and Harrison (1953).
163	27N	66W	10	Guernsey Lake	Love (1954).
164	28N	70W	18	Horseshoe Creek	Do.
165	29N	67W	28	Sand Canyon	Do.
				Sheridan County	
168	55N	86W	35	Big Goose Creek	Agatston (1954).
169	56N	87W	23	Little Tongue River	Wilson (1954).
170	57N	87W	33	Amsden Creek	Love (written commun., 1956).
171	58N	89W	6	Little Bighorn River	Agatston (1954).
				Sublette County	
175	39N	109W	36	Sheep Mountain	Love (1954).
				Teton County	
179	38N	115W	3	Hoback Canyon	Love (written commun. 1956).
180	40N	112W	28	Darwin Peak	Love (1954).
181	40N	116W	16	Jackson	Do.
182	42N	113W	34	Crystal Creek	Do.
183	42N	115W	2	Flat Creek-Sheep Creek.	Do.
				Washakie County	
187	41N	88W	5	Trout Creek	Agatston (1954).
188	42N	88W	2	Hampton Ranch	Do.
189	45N	86W	9	Otter Creek	Do.
190	47N	88W	1	Tensleep Canyon	Love (written commun. 1956).
				Yellowstone National Park	
197	lat 44°55′ N; long 110°50′ W			Quadrant Mountain	Scott (1935).

SUBSURFACE

No. on pls. 1-3	Location T.	Location R.	Location Sec.	Company	Well name	Source of data
				Albany County		
12	13N	73W	8	Western Oil Fields.	Klink 1	Maughan and Wilson (1960).
				Albany County—Continued		
13	13N	76W	15	Coulston and Harrel.	Schmidt 1	American Stratigraphic Co.
14	16N	75W	36	Mississippi River Fuel.	State 1	Do.
15	17N	76W	18	California	Wilson 8	Wyoming Geol. Assoc. (1956).
16	19N	76W	9	U.S. Smelting and Refining.	Unit 19-76 1-9.	American Stratigraphic Co.
17	24N	76W	25	Wasatch Oil	Swan 1-25	Do.
				Big Horn County		
21	49N	89W	19	Geo. Nolan	Government 1	American Stratigraphic Co.
22	49N	91W	2	Shell Oil	Government 1	Do.
23	50N	92W	2	Kerr McGee-Phillips Petro eum.	Unit 1	Do.
24	51N	90W	33	Davis Oil	Government 1	Do.
25	51N	93W	24	Stanolind Oil	Orchard Unit 1	Do.
26	52N	92W	10	Texas	Linderman 1	Do.
27	52N	93W	20	Osborne	Krueger 1	Do.
28	54N	95W	11	Mule Creek Oil and Atlantic Refining.	Unit 2	Do.
29	55N	92W	15	Continental Oil	Government 1	Do.
30	55N	97W	26	Stanolind Oil	J. E. Pepper 1	Do.
31	56N	96W	12	Texas	Community 1	Do.
32	56N	97W	28	Ohio Oil	G. Easton Unit 6.	American Stratigraphic Co.
33	57N	97W	7	Sohio Petroleum and Barnsdall Oil.	Dorothy Fox 2	Do.
34	58N	96W	34	Mohawk Petroleum.	Government 1	Do.
				Carbon County		
39	13N	89W	17	Carter Oil	Unit 1	American Stratigraphic Co.
40	14N	83W	23	Allphin	Peterson 1	Phillips Petroleum Co.
41	16N	84W	10	Continental Oil	Unit 1	American Stratigraphic Co.
42	16N	84W	24	Continental Oil	Unit 2	Phillips Petroleum Co.
43	17N	85W	31	Aurora-Kingwood	Unit 1	American Stratigraphic Co.
44	17N	88W	27	Shell Oil	Rawlins 1	Do.
45	17N	89W	23	Wasatch Oil	Government-Unit 1.	Do.
46	19N	88W	2	Ohio Oil	Government 4	Ritzma (1951).
47	20N	81W	14	Texas	Unit 1	American Stratigraphic Co.
48	20N	78W	35	Ohio Oil	Harrison Cooper 15.	Wyoming Geol. Assoc. (1956).
49	21N	86W	28	Sinclair Oil and Refining.	Unit 1	American Stratigraphic Co.
50	22N	78W	26	California	Hodges 1	Do.
51	23N	78W	34	McCulloch Oil	Government-Macson 1.	Do.
52	24N	80W	13	National Assoc. Petro eum.	U.P.R.R. 1	Do.
53	25N	84W	25	Mississippi River Fuel.	Unit 1	Do.
54	25N	86W	34	Atlantic Refining and Fremont Petroleum.	Unit 3	Do.
55	26N	78W	15	J. J. Lynn	Burk 1	Do.
56	26N	80W	17	Amerada Petroleum and Sohio Petroleum.	Sullivan Co. 1	Do.
57	26N	89W	24	Sun Oil and others.	Government-Hintze 1.	American Stratigraphic Co.
58	27N	86W	4	Sinclair Oil and Gas.	Unit 1	Do.
59	28N	81W	22	Stanolind Oil	Unit 1-A	Do.
60	12N	92W	10	Phillips Petroleum.	Unit 8	Do.
				Converse County		
67	31N	69W	20	California	Nylen-Gillespie 1.	American Stratigraphic Co.
68	33N	69W	13	Carter Oil	Rose Neiman 1	Do.
69	33N	76W	9	Continental Oil	Whitesides 60	Love (1954).

No. on pls. 1-3	Location			Company	Well name	Source of data
	T.	R.	Sec.			
Fremont County						
81	1S	4E	36	Atlantic Refining	Tribal 5	Agatston (1957).
82	2S	2E	19	Stanolind Oil	Terry 3	American Stratigraphic Co.
83	7N	1E	30	Carter Oil	Shoshone-Madden 1.	Love (written commun., 1956).
84	1N	1W	27	Continental Oil	Sage Creek 2	American Stratigraphic Co.
85	2N	1W	19	Stanolind Oil	Tribal 9-A	Love (1954).
86	3N	1W	6	British American	Tribal E-6	Wyoming Geol. Assoc. (1956).
87	6N	2W	15	Continental Oil	Chatterton 20	Love (written commun. 1956).
88	27N	95W	18	Gulf Oil	Government 1	Agatston (1957).
89	28N	94W	2	California	Unit-Government 3.	American Stratigraphic Co.
90	29N	96W	20	Carter Oil	Yellowstone-Sheep Co. 1.	Do.
91	30N	95W	14	California	Government 1	Do.
92	31N	94W	5	British American	Government 1	Do.
93	31N	98W	4	W. A. Barber and others.	Government 1	American Stratigraphic Co.
94	32N	95W	14	Sinclair-Wyoming.	Unit 9	Do.
95	33N	92W	1	Sinclair Oil and Gas.	Unit 2-C	Love (1954).
96	33N	96W	10	Stanolind Oil	Unit 11	Do.
97	42N	107W	6	California	Langguth 1	American Stratigraphic Co.
Hot Springs County						
100	8N	3E	6	Candana Southern	Tribal 1	American Stratigraphic Co.
101	41N	91W	27	Sohio Petroleum	Picard 1	Do.
102	42N	96W	2	Shell Oil	Unit 1	Do.
103	43N	91W	6	Farmer's Union	Murphy 1	Love (written commun., 1956).
104	43N	92W	21	Pacific West	Kirby Creek 1	Do.
105	44N	95W	23	Continental Oil	Gebo 42-T	American Stratigraphic Co.
106	44N	97W	12	Husky Oil	Unit 5	Do.
107	45N	100W	26	Continental Oil	Skelton Unit 1	Do.
108	46N	98W	25	Texas	Government-Walton 1.	Do.
109	46N	100W	25	Ohio Oil and Stanolind Oil.	Sheep 1	Do.
Johnson County						
115	42N	83W	4	Chicago Corporation and Republic Natural Gas.	Harlan 1	American Stratigraphic Co.
116	44N	81W	19	Stanolind Oil	Government-Maine 1.	Do.
117	45N	83W	24	Stanolind Oil	Brock 1	Do.
118	46N	81W	5	Shell Oil	Government 1	Foster (1958).
119	48N	76W	20	Pure Oil	Unit 1	American Stratigraphic Co.
120	48N	82W	17	Carter Oil	Rider 3	Do.
Natrona County						
131	29N	80W	22	Tidewater Associates.	Lawn Creek 81-22.	American Stratigraphic Co.
132	31N	81W	24	Pacific Western Oil.	Oborne 1	Love (1954).
133	31N	84W	9	Atlantic Refining	Foster Unit 1	American Stratigraphic Co.
134	32N	81W	16	Kemmerer and Kemmerer.	State 1	Do.
135	33N	80W	20	M. E. Morton	Johnson 1-A	Do.
136	34N	82W	10	Skelly Oil	Wallway-Government 1.	Do.
137	35N	77W	21	Socony-Vacuum	G 32-X-21	Do.
138	36N	81W	4	Amerada Petroleum.	Unit 1	Do.
139	36N	82W	22	Cities Service	Sprecher 1	Do.
140	37N	82W	36	Pure Oil	Unit 1	Do.
141	37N	85W	3	Trigood Oil	Government 10.	Do.
142	38N	78W	10	U.S. Navy	NPR3 1-G-10	Do.
143	39N	83W	18	Sohio Petroleum	Government-Evans 1.	Do.

No. on pls. 1-3	Location			Company	Well name	Source of data
	T.	R.	Sec.			
Natrona County—Continued						
144	40N	79W	35	Stanolind Oil	Government 1	Love (written commun., 1960).
145	40N	80W	31	Shell Oil	Unit-Government Hill 1.	American Stratigraphic Co.
Park County						
146	47N	100W	28	General Petroleum.	Renner 1	Love (written commun., 1960).
147	47N	102W	20	Continental Oil	Government 1	American Stratigraphic Co.
148	48N	100W	34	Stanolind Oil	Unit 2	Agatston (1954).
149	48N	101W	4	California	Rawhide 1	American Stratigraphic Co.
150	48N	103W	31	Wilshire-Atlantic	State 1	Agatston (1954).
151	49N	102W	13	Texas	Unit 3	American Stratigraphic Co.
152	50N	100W	13	Sohio Petroleum	Simmons-Government 1.	Do.
153	50N	101W	6	Richfield	Unit 1	American Stratigraphic Co.
154	50N	105W	25	Continental Oil	Unit 1	Do.
155	51N	100W	29	Kirk-Pacific Western.	Connagham 5	Do.
156	52N	101W	31	Superior Oil	Unit 1	Do.
157	53N	100W	27	California	Unit 1	Do.
158	55N	100W	8	Stanolind Oil	Unit 1	Do.
159	57N	98W	8	Continental Oil	Government 1	Do.
160	57N	101W	7	General Petroleum.	Badura 2	Do.
161	58N	100W	33	Seaboard Oil	53-NP	Do.
Platte County						
166	25N	65W	29	Seaboard Oil	Wilson 1	American Stratigraphic Co.
167	30N	67W	2	National Associated Petroleum.	Government 1	Love (written commun., 1960).
Sheridan County						
172	55N	85W	22	Shell Oil	Demple 1	American Stratigraphic Co.
173	57N	78W	11	Shell Oil	Clear Creek 1	Do.
174	58N	84W	30	Shell Oil	Buszkiesevic 1	Do.
Sweetwater County						
176	16N	104W	21	Mountain Fuel	Unit 1	Verville and Momper (1960).
177	19N	102W	35	Cities Service	Union Pacific	American Stratigraphic Co.
178	19N	104W	11	Mountain Fuel	Union Pacific 4	American Stratigraphic Co.
Teton County						
184	42N	114W	1	Carter Oil	Marie Treglown 1.	American Stratigraphic Co.
185	44N	111W	25	California	Unit 1	Do.
Uinta County						
186	16N	117W	32	Shell Oil	LeRoy Unit 1	Verville and Momper (1960).
Washakie County						
191	43N	89W	31	Hiawatha	Government 1-31.	American Stratigraphic Co.
192	45N	92W	19	G & G Drilling	Unit 1	Do.
193	46N	91W	26	General Petroleum.	43-26-G	Love (written commun., 1956).
194	46N	96W	27	Phillips Petroleum.	Unit 1	American Stratigraphic Co.
195	48N	89W	31	Gulf Oil	Mills-Federal 1	Do.
196	48N	92W	18	Pure Oil	Unit 1	Do.

269-091 O—67——3

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