Stratigraphy, Age, and Paleotectonic Significance of the Cottonwood Canyon Member of the Madison Limestone in Wyoming and Montana

GEOLOGICAL SURVEY BULLETIN 1251-B

Stratigraphy, Age, and Paleotectonic Significance of the Cottonwood Canyon Member of the Madison Limestone in Wyoming and Montana

By CHARLES A. SANDBERG *and* GILBERT KLAPPER

CONTRIBUTIONS TO GENERAL GEOLOGY

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A comprehensive study of the facies relations and conodont zonation of transgressive marine beds that straddle the Devonian-Mississippian boundary in the Northern Rocky Mountains

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 – Price 30 cents (paper cover)

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CONTRIBUTIONS TO GENERAL GEOLOGY

STRATIGRAPHY, AGE, AND PALEOTECTONIC SIGNIFICANCE OF THE COTTONWOOD CANYON MEMBER OF THE MADISON LIMESTONE IN WYOMING AND MONTANA

By CHARLES A. SANDBERG and GILBERT KLAPPER [1]

ABSTRACT

The dark shale unit of Devonian and Mississippian age is herein named the Cottonwood Canyon Member of the Madison Limestone in Wyoming and of the Lodgepole Limestone in Montana and extreme western Wyoming, where the Lodgepole is the basal formation of the Madison Group. The type section is described from excellent exposures on the north wall of Cottonwood Canyon on the west side of the northern Bighorn Mountains, near Lovell, Wyo. A reference section is established in the Beartooth Mountains and a subsurface reference section, based on core descriptions, is established in the Bighorn Basin.

The Cottonwood Canyon Member, which ranges in thickness from 0 to 80 feet, is recognized to be largely continuous in a 50,000-square-mile area of northern and western Wyoming and southern and central Montana. In Wyoming the member grades into and intertongues with other strata in the lower part of the Madison Limestone, whereas in Montana and extreme western Wyoming it generally lies at the base of the Lodgepole Limestone. The Cottonwood Canyon generally overlies an irregular erosion surface that represents part of an interregional unconformity. In the report area it rests on rocks ranging in age from earliest Mississippian to Late Cambrian, but farther south it rests on the Precambrian.

The Cottonwood Canyon Member is divided into a lower and an upper tongue, each of which is further divisible into an eastern, dolomitic facies and a western, shale and siltstone facies. Both tongues are characterized by basal conglomeratic lag deposits containing abundant phosphatic nodules and coprolites, conodonts, fish remains, and glauconite grains. The lag deposits are continuous between the facies of each tongue, and the lag deposit of the upper tongue also continues at the base of the Lodgepole Limestone, even where the upper tongue is too thin to be differentiated.

Four conodont zones are recognized within the Cottonwood Canyon Member. They are, in ascending order, the Lower *Spathognathodus costatus* (upper *to*V) Zone, which indicates a very late Devonian age for the lower tongue, and

[1] Pan American Petroleum Research Center.

the *Siphonodella sulcata* (lower *cu*I), *S. sandbergi–S. duplicata* (upper *cu*I), and Lower *S. crenulata* (lower *cu*IIα) Zones, which indicate an Early Mississippian (Kinderhook) age for the upper tongue. The *S. sandbergi–S. duplicata* Zone, which is named herein, contains a succession of two distinct faunas. The older of the two faunas is recognized at only two localities, however, and no formal subdivision of this zone is proposed at present.

All the conodont zones that are present in the Cottonwood Canyon Member, except for the *Siphonodella sulcata* Zone, also have been found in the lower, undifferentiated part of the Madison or Lodgepole Limestone. Because the undifferentiated lower part of the Madison contains the Lower *Spathognathodus costàtus* Zone in some areas of Wyoming, its age there must now be regarded as Mississippian and Devonian.

Two conodont zones are recognized in the Three Forks Formation, which unconformably underlies the Cottonwood Canyon Member, in Montana. These are, in ascending order, the *Scaphignathus velifera* (upper *to*IIIα–lower *to*IV) Zone, which is widespread in the top of the Trident Member of Late Devonian (Famennian) age, and the Upper *Polygnathus styriaca* (lower *to*V) Zone, which is found in the base of the overlying Sappington Member. The presence of this zone at the base and of a spore flora containing *Leiozonotriletes naumovae* near the top indicates a very late Devonian age for the bulk of the Sappington. Although the uppermost unit of the Sappington may be partly Mississippian, a reevaluation of previously cited conodont evidence provides no support for a Mississippian age designation.

Representative conodont collections are listed from all the described units to document the conodont zonation.

The tongues of the Cottonwood Canyon Member are interpreted to represent the basal deposits of two separate eastward transgressions of a Madison sea from the Cordilleran miogeosyncline. The earlier transgression in very late Devonian time was initially confined to narrow embayments and was less widespread. The later transgression in Early Mississippian time was much more widespread, and the report area and areas to the north and east were inundated. A mild orogenic episode, probably related to the Antler orogeny of Nevada and Idaho, intervened between the two transgressions in latest Devonian and earliest Mississippian time.

INTRODUCTION

The name Cottonwood Canyon Member of the Madison Limestone (or of the Lodgepole Limestone in areas where the Lodgepole is the basal formation of the Madison Group) is here applied to the informal dark shale unit of Sandberg (1963). The member is largely continuous in an area of about 50,000 square miles in northern and western Wyoming and in southern and central Montana (fig. 1). The units directly underlying the member are shown in figure 2.

PURPOSE AND SCOPE OF REPORT

The report demonstrates that the Cottonwood Canyon Member contains two tongues separated by a disconformity and that it is characterized by conglomeratic lag deposits related to two transgressions of a Madison sea. Four distinct conodont zones in the member and laterally equivalent beds of the Madison Limestone (or Group) are recognized and described. On the basis of these zones, the age of the Cottonwood Canyon Member and of equivalent beds in the basal part of the Madison is shown to range from very late Devonian (*Clymenia*-Stufe,[2] upper *to*V [3]) to Early Mississippian (*Pericyclus*-Stufe, lower *cu*IIα).

PREVIOUS WORK

Many published reports have described the stratigraphy or paleontology of the Madison Limestone (or Group) in small areas of Montana and Wyoming, and several have treated these subjects regionally. Few papers, however, have discussed the basal beds, their conodont faunas, or the lower contact of the Madison in the area of the present report, and only these are cited here.

The clastic content of basal deposits of a transgressive Madison sea in Wyoming was mentioned by Andrichuk (1955) in one of the first modern regional studies of the Madison Group. On the east side of the Bighorn Mountains, near North Crazy Woman Canyon (fig. 1), Hose (1955) noted that the lower 3 feet of the Madison is slightly sandy and locally conglomeratic. In the Teton Range, Wyo. (fig. 2), a black shale at the base of the Lodgepole was recognized by Sando and Dutro (1960), but they regarded it as a part of underlying formations. Similarly, Blackstone and McGrew (1954), at Cottonwood Canyon, and Klapper (1958), at Bull Lake and Dinwoody Canyons in the Wind River Range, Wyo. (fig. 1), recognized thin beds of black shale near the base of the Madison but included them in the top of underlying Devonian formations.

Sandberg (1963) advanced the present concept of a single widespread clastic unit that is comprised of shale and siltstone in some areas and of silty or sandy dolomite in others and that incorporates all the above-mentioned occurrences as well as many others. The stratigraphy of the various Devonian formations that successively underlie this unit unconformably was described by Sandberg (1965).

Conodonts in beds of black shale at Cottonwood Canyon were first

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[2] As the term "Stufe" (plural, "Stufen") is in good standing in Germany and elsewhere, it is not desirable to translate it.

[3] These letter-numeral designations are standard map symbols in Germany. The first letter *t* is applied arbitrarily to Devonian (to avoid confusion with Diluvium), and the first letter *c* is applied to Carboniferous. The second letter *o* stands for "ober," or upper, and the second letter *u* stands for "unter," or lower. Thus *to* is Upper Devonian and *cu* is Lower Carboniferous. Roman numerals used in this report stand for the following Devonian and Carboniferous ammonoid Stufen: *Manticoceras* (*to*I), *Cheiloceras* (*to*II), *Platyclymenia* (*to*III–IV), *Clymenia* (*to*V), *Wocklumeria* (*to*VI), *Gattendorfia* (*cu*I), and *Pericyclus* (*cu*II). Lowercase Greek letters—α, β, δ—are used in ascending order for subdivisions of these Stufen.

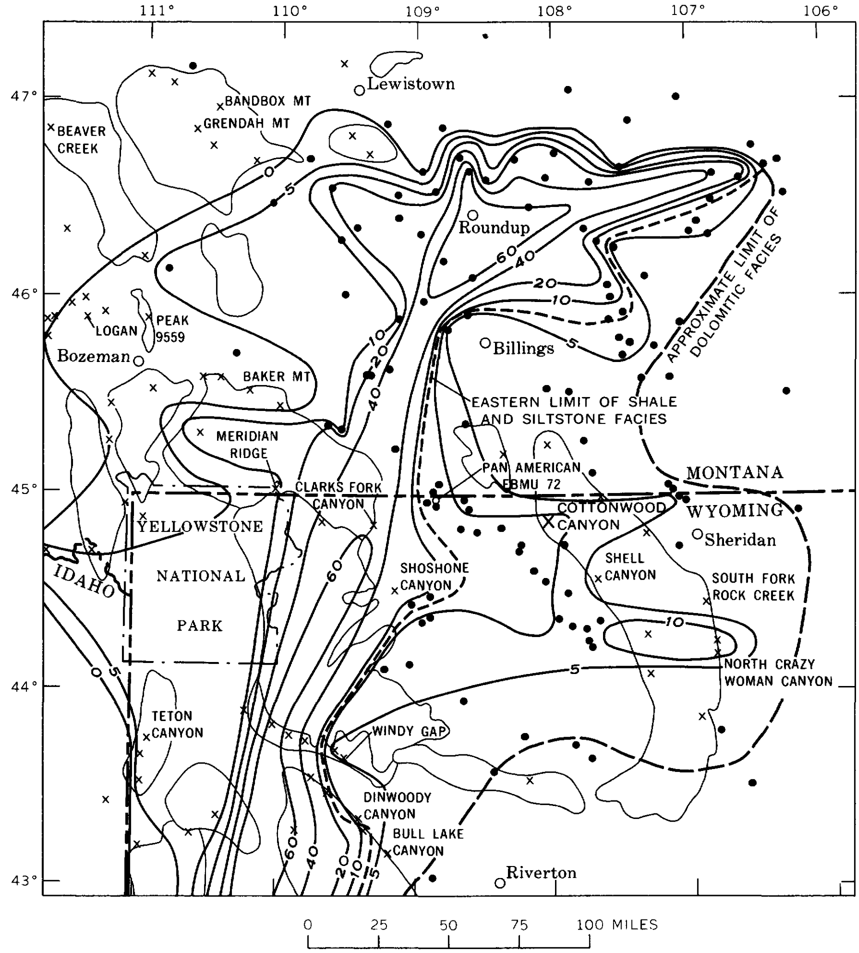

Figure 1.—Isopach and facies map of Cottonwood Canyon Member of Madison Limestone. Only critical (0-, 5-, 10-, 20-, 40-, and 60-ft.) isopachs are shown. Location of measured sections (x), type section (X), subsurface reference section (Pan American EBMU 72), and control wells (●). Mountain ranges are outlined; names of mountain ranges and basins are shown in figure 2.

reported by Blackstone and McGrew (1954) and were described and illustrated by Ethington, Furnish, and Wingert (1961). A second and younger fauna from higher beds of the same unit at Cottonwood Canyon was reported by Sandberg (1963) and described and illustrated by Klapper (1966).

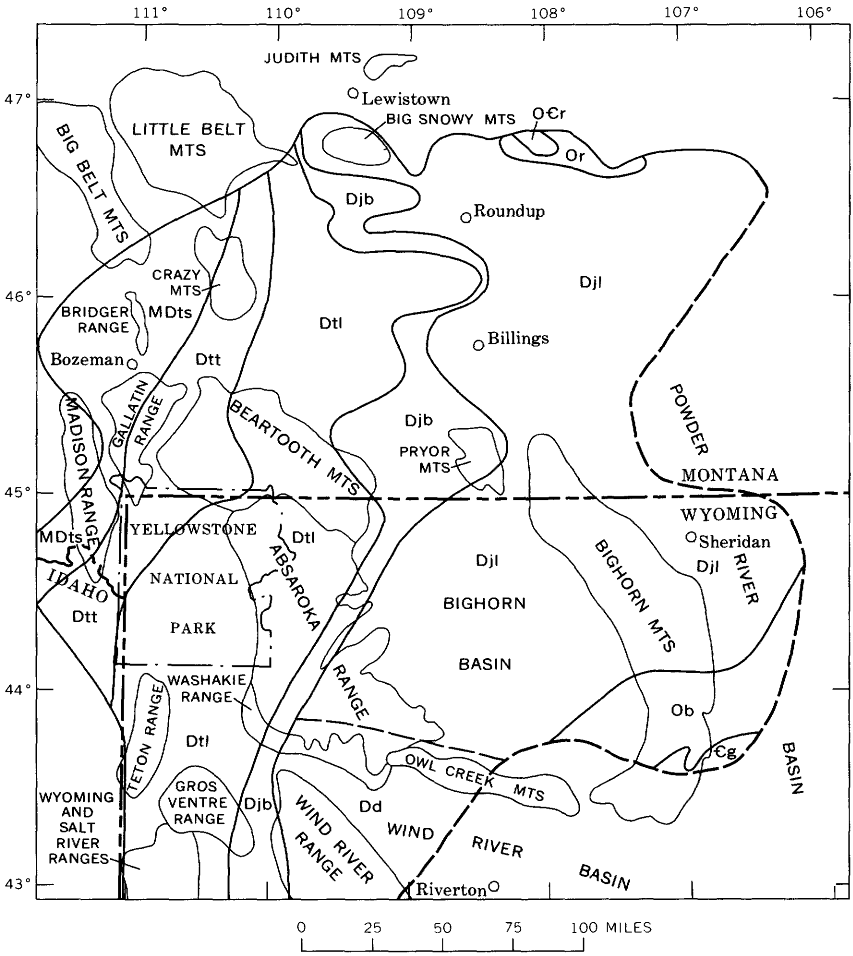

FIGURE 2.—Distribution of geologic units directly underlying main body of Cottonwood Canyon Member of Madison Limestone. MDts, Sappington Member of Three Forks Formation; Dtt, Trident Member of Three Forks Formation; Dtl, Logan Gulch Member of Three Forks Formation; Djb, Birdbear Member of Jefferson Formation (surface) or equivalent Birdbear Formation (subsurface); Djl, lower member of Jefferson Formation (surface) or equivalent Duperow Formation (subsurface); Dd, Darby Formation; Ob, Bighorn Dolomite; Or, Red River Formation; O€r, undivided Upper Cambrian and Lower Ordovician rocks; €g, Gallatin Limestone.

Conodonts from beds that are now included in the Cottonwood Canyon Member at other localities in Montana and Wyoming were reported by Koucky, Cygan, and Rhodes (1961), Koucky and Rhodes (1963), and Sandberg (1963) and were described and illustrated by Klapper (1958, 1966).

SOURCES OF DATA

This report is a product of close cooperation between the two authors since 1960. Because of obligations to their respective organizations or institutions, they have hitherto published their related findings independently, while freely exchanging new concepts and advance data and coordinating their investigations to prevent duplication of effort.

Since 1954, Sandberg has been engaged in a regional study of the lowermost Mississippian, Devonian, and older Paleozoic rocks of the Williston basin and Northern Rocky Mountains. In correlating newly established lithologic units throughout this region, emphasis was placed on the recognition and delineation of widespread unconformities. Two major interregional unconformities, whose criteria for recognition had previously not been well established in this region, were discerned. One of these, which is locally at the base of Upper, Middle, or Lower Devonian rocks, has been discussed in previous reports. The other, which is more complex and lies near the Mississippian-Devonian boundary, is considered in detail here.

Early in his investigation, Sandberg realized that conodonts, which are highly abundant above and less abundant below this latter unconformity, might be the most useful single group of fossils for dating the unconformity and for precisely locating the Devonian-Mississippian boundary. Megafossils were found to be relatively scarce and commonly poorly preserved in the largely dolomitic rocks of the region, so that phylogenetic sequences of individual groups across the unconformity could not be established. Sandberg also realized that age determinations based on the indiscriminate use of different, locally abundant groups of megafossils might provide conflicting age determinations.

Klapper became interested in conodont zonation of Devonian and lowermost Mississippian rocks as a result of his study of conodont faunas from the Wind River Range (Klapper, 1958). During his investigations toward a doctoral dissertation at the University of Iowa, Klapper was directed by Sandberg to several important conodont localities at previously measured sections. In return, Klapper provided many useful conodont determinations and information about newly discovered localities. This exchange of information continued after completion in 1962 of Klapper's thesis on Upper Devonian and Lower Mississippian conodont zones in Montana, Wyoming, and South Dakota.

During the 1965–66 field seasons, the authors spent several weeks in Montana and Wyoming resolving their minor differences and searching for new conodont localities in critical areas. This collaboration proved so successful that the preliminary reports (Sandberg, 1963;

Klapper, 1966) became outdated. Consequently, the present report was written to make the necessary corrections and to present the latest findings.

ACKNOWLEDGMENTS

The contributions of many U.S. Geological Survey personnel are gratefully acknowledged. W. H. Hass provided determinations of several conodont collections during the early phase of investigation until his death in 1959. J. W. Huddle provided many determinations of conodont collections beginning in 1964. R. F. Gantnier and J. A. Thomas made the calcium-magnesium analyses for the type section and Clarks Fork Canyon reference section of the Cottonwood Canyon Member. W. R. Keefer, M. R. Mudge, J. F. Murphy, W. G. Pierce, A. E. Roberts, G. D. Robinson, B. A. L. Skipp, and I. J. Witkind, all experienced in mapping in the Northern Rocky Mountains, constructively criticized the preliminary nomenclature. Special thanks are expressed to J. F. Murphy, J. T. Dutro, Jr., and W. J. Sando, who visited many of the measured sections with the authors during the summer of 1965, critically reviewed the field evidence, and enthusiastically supported the preparation of this report.

The authors are also grateful to A. L. Benson, who freely exchanged ideas and information during the preparation of his doctoral dissertation at the Ohio State University. A condensed version of Benson's thesis (1966) includes a description of the stratigraphy of the Cottonwood Canyon Member in western Wyoming.

The authors express their thanks to the Pan American Petroleum Corp. and other operators of the Elk Basin oil field for permission to examine cores of the Pan American 72 Elk Basin Madison Unit well and to publish the lithologic descriptions that establish a subsurface reference section for the Cottonwood Canyon Member. J. A. McCaleb, Pan American Petroleum Corp., accompanied the authors during the 1965 field season and later facilitated examination of the cores.

AGE AND STRATIGRAPHIC RELATIONS OF UNDERLYING UNITS

The Cottonwood Canyon Member rests unconformably, and locally with marked angularity, on rocks ranging in age from Mississippian to Cambrian within the report area (fig. 2) and on Precambrian rocks in isolated areas in southeastern Wyoming.

The youngest unit that lies directly below the Cottonwood Canyon Member is the Sappington Member of the Three Forks Formation in the vicinity of the Bridger Range in southwestern Montana (fig. 2). The precise age of the top of the Sappington has not yet been firmly fixed in terms of the conodont zonation (fig. 3), but it is possibly Early Mississippian.

The age and stratigraphic relations of the Sappington are important not only to the dating of the regional unconformity but also to the correlation of the Cottonwood Canyon Member. Consequently, they are evaluated in more detail than the ages and stratigraphic relations of the other unconformably underlying rocks.

The Sappington Member is largely a regressive marine deposit consisting mostly of calcareous and dolomitic siltstone, in which conodonts are relatively scarce and generally poorly preserved. The Sappington was divided into five units, numbered from base to top, by Sandberg (1965). Its lowermost unit (1) is a thin brownish-gray to black carbonaceous shale locally containing a very thin transgressive sandstone at or near the base. A poorly preserved conodont fauna was obtained by Klapper (1966) from a sandstone within this shale at a locality 1½ miles north of Peak 9559 in the Bridger Range (fig. 1). More recently, a large diverse well-preserved conodont fauna was found by Sandberg in a conglomeratic lag deposit at the base of the Sappington at Bandbox Mountain in the Little Belt Mountains (fig. 1).

Faunas from both localities are assigned to the Upper *Polygnathus styriaca* Zone (lower *to*V). This assignment dates the base of the Sappington Member as very late Devonian but unequivocally older than the base of the Cottonwood Canyon Member at any locality (fig. 3).

Although most workers would now agree that some part of the Sappington Member is Mississippian, the exact placement of the Devonian-Mississippian boundary on the basis of brachiopod assemblages continues to evoke considerable controversy. (See Gutschick and Rodriguez, 1967.) Turning to another possible method of dating, Sandberg (1965) reported the occurrence in the Sappington of a large continental spore flora, which was dated as latest Devonian by R. H. Tschudy. The most significant element of this flora is *Leiozonotriletes naumovae* Balme and Hassell (1962), which is apparently restricted to the Devonian and has a cosmopolitan distribution in beds of known latest Devonian age in Western Australia, Colombia, Libya, and western Canada (R. H. Tschudy, written commun., Feb. 14, 1962) and in Belgium, Germany, Russia, Ohio, and New York.

In the Canning Basin of Western Australia, *Leiozonotriletes naumovae* is considered by Balme and Hassell (1962) to be the key species of the Upper Devonian. There, it occurs in beds of the Fairfield Formation with conodonts that are not younger than latest Devonian. In fact, the youngest conodont fauna recognized in the Fairfield is

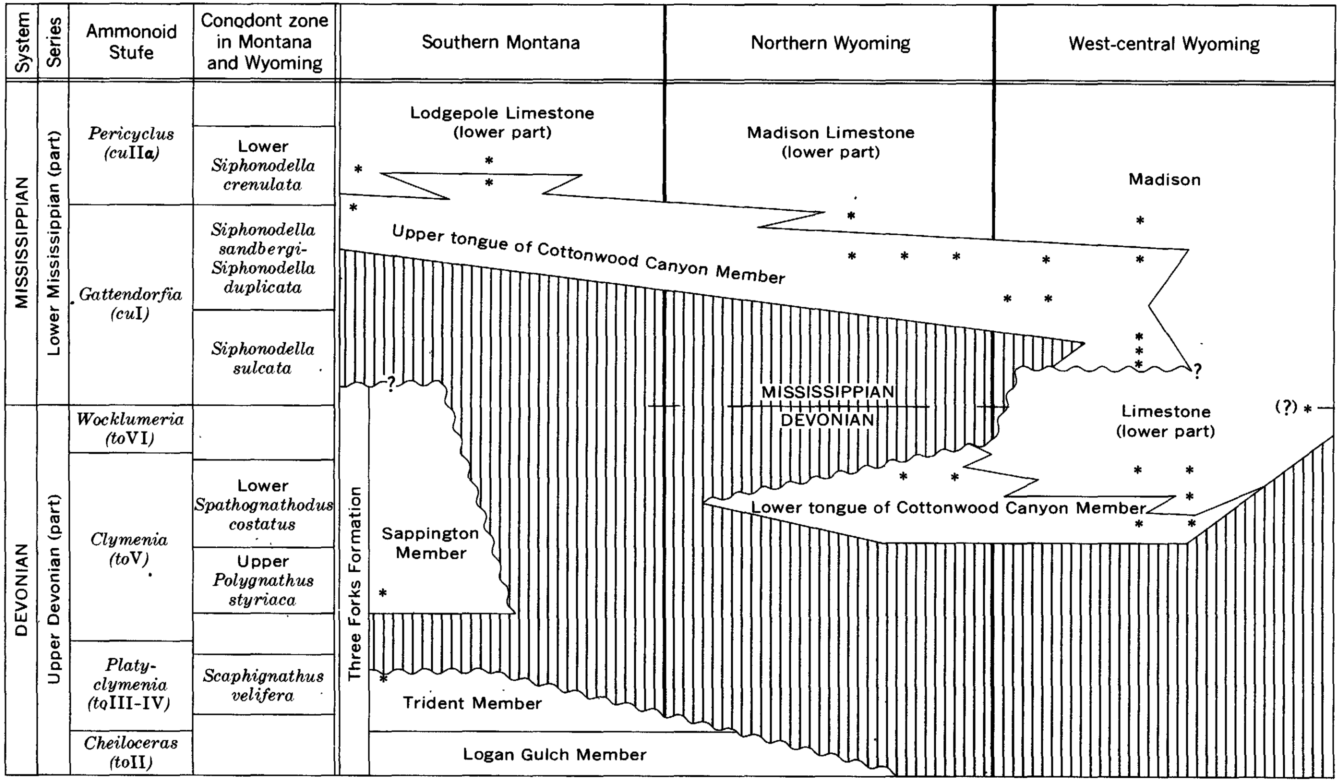

Figure 3.—Age, conodont zones, and stratigraphic relations of Lodgepole and Madison Limestones, Cottonwood Canyon Member, and Three Forks Formation. Ammonoid Stufen from House (1962); Devonian conodont zones from Ziegler (1962); Mississippian conodont zones modified from Voges (1959), and Collinson, Scott, and Rexroad (1962); * indicates position of diagnostic conodont collection.

slightly older than latest Devonian and was assigned by Glenister and Klapper (1966, p. 838, sample GSWA 3240) to either the Lower or Middle *Spathognathodus costatus* Zone (upper *to*V–lower *to*VI).

Although the upper range limit of *Leiozonotriletes naumovae* has not been established in terms of conodont zonation on a worldwide basis, it has been firmly fixed in Belgium as a result of a recent palynological study by Streel (1966). *L. naumovae* of the Sappington appears to be included in a phylogenetic sequence of spores that was designated by the key species *Hymenozonotriletes lepidophytus* Kedo sensu lato and used as a basis for zonation by Streel (1966). *H. lepidophytus* occurs throughout the Strunian (*Tn*1a) of Belgium, which is equated by Streel (1966) and other workers to the *Wocklumeria*-Stufe (*to*VI) of Germany. It occurs no higher than the top of the Devonian (Strunian) in Belgium, and its highest occurrence there is below the lowest recognized occurrence of the conodont *Siphonodella* (Streel, 1966, p. 80).

The position of the spore flora of the Sappington has recently been established in terms of both ammonoid and conodont zonation in the classic Devonian section of Germany. The Sappington flora has been correlated through similar floras in Alberta to a spore flora, recognized by M. Streel in the Hangenberg Shale of the Hönnetal section in Germany (H. S. Walton and David Mason, oral commun., Apr. 21, 1967). The Hangenberg Shale, which is dated as latest Devonian (*Wocklumeria*-Stufe, *to*VI), directly underlies the Hangenberg Limestone, whose base is Lower Carboniferous (*Gattendorfia*-Stufe, lower *cu*I).

In Montana, the spore flora containing *Leiozonotriletes naumovae* occurs near the top of unit 4 in a bed of shale 23 feet below the top and 42 feet above the base of the Sappington Member at Peak 9559. The presence of this flora so close to the top of the Sappington suggests that the Sappington is almost entirely Devonian and that only its uppermost part, unit 5 of Sandberg (1965), may contain beds of Mississippian age.

Conodonts appear to be present in the top few inches of unit 5 of the Sappington Member at Logan, Mont. (Achauer, 1959), and at other nearby localities (fig. 1). They are absent, however, in lithologically similar underlying beds of the member. Although poorly preserved and difficult to separate from the rock, the conodonts that supposedly come from the top of the Sappington are unquestionably siphonodellids, which indicate an age younger than earliest Mississippian. A detailed reexamination of the upper contact of the Sappington at Mud Spring Gulch, 10 miles northwest of Logan, and at Ingleside Quarry, 12 miles west of Logan (fig. 1), revealed the presence of a previously unrecognized very thin conodont-rich basal lag deposit of the Cottonwood Canyon Member at these localities. Because of the abundance of conodonts in this lag deposit and because of the absence of conodonts from lower beds of the Sappington, it seems more logical to refer all thin beds from which conodonts are reported at the top of the Sappington to the Cottonwood Canyon. However, even if some of the beds near the contact are indeed Sappington, the possibility that the conodonts have infiltrated downward through cracks from a lag deposit above an unconformity cannot be eliminated at present. Stratigraphic leak of conodonts into the top 1 inch of the Sappington has been observed at Beaver Creek (fig. 1) and, as will be discussed later, into other beds as low as 6 feet beneath the Cottonwood Canyon Member elsewhere. Consequently, in the absence of firm conodont evidence, the Early Mississippian age assignment of the top of the Sappington, although quite possible, is considered tentative and is so indicated in figure 3.

The Sappington is restricted largely to southwestern Montana (fig. 2), owing to its eastward truncation beneath the Cottonwood Canyon Member. Because of this truncation, successively lower units of the Sappington cap the member as it thins toward its eastern limit. The overall thinning of the Sappington does not result from depositional thinning of its units nor from the disappearance of units at its base by onlap, as demonstrated by measured sections in the eastern Little Belt Mountains. There, at Bandbox and Grendah Mountains (fig. 1) and at several other localities close to it its eastern limit, the Sappington is 5–9 feet thick, and only its basal two units (1, 2) are preserved beneath a half-inch-thick lag deposit, related to the Cottonwood Canyon Member, at the base of the Lodgepole Limestone. Significantly, unit 2, which caps the Sappington at these localities, is 3–7 feet thick. This thickness range is the same as that of unit 2 in the vicinity of Logan, where the Sappington attains a maximum thickness and all five units are present (Sandberg, 1965 p. 14–15).

The Sappington is underlain by the Trident Member of the Three Forks Formation in southwestern Montana. There, at Peak 9559, Sheep Mountain, and probably at Mud Spring Gulch, the uppermost beds of the Trident contain a conodont fauna assigned to the *Scaphignathus velifera* Zone (fig. 3). This fauna is Upper Famennian (Bouckaert and Ziegler, 1965) and confirms previous age determinations of the Trident based on ammonoids and brachiopods from lower beds.

Two conodont zones, the Lower *Polygnathus styriaca* and the Middle *P. styriaca* Zones of Ziegler (1962), are as yet unrecognized between conodont zones in the top of the Trident and in the base of the Sappington Member. As the Sappington does not overstep rocks older than the Trident, the break below the Sappington (fig. 3) is interpreted as a disconformity in southern Montana. This disconformity may have some regional significance, however, because it extends northward into Alberta, where it underlies the Exshaw Formation.

East of the limit of the Sappington, the Cottonwood Canyon Member rests unconformably on the Trident and Logan Gulch Members of the Three Forks Formation in descending order (fig. 3). The weakly resistant Trident Member, which is largely greenish-gray calcareous shale, is truncated in a belt 10–50 miles wide. It extends only about 25 miles into Yellowstone National Park in the northwest corner of Wyoming (fig. 2). Farther east, the Logan Gulch, which comprises silty dolomite, dolomitic siltstone, and evaporite-solution breccia in Wyoming, is truncated in a belt about 65 miles wide. It underlies the Cottonwood Canyon at Meridian Ridge in the northeast corner of Yellowstone Park (fig. 1) and is the only member of the Three Forks that is widespread in western Wyoming. The eastern limit of the Logan Gulch lies along the west side of the Bighorn Basin, as shown in figure 2. The contact with the overlying Cottonwood Canyon is well exposed at the Clarks Fork Canyon reference section on the east side of the Beartooth Mountains (fig. 1), where the Logan Gulch is only 15 feet thick close to its wedge edge.

Beyond the limit of the Three Forks Formation, the Cottonwood Canyon Member unconformably overlies the resistant but thin subsurface Birdbear Formation (or the exactly equivalent outcropping Birdbear Member at the top of the Jefferson Formation). The Birdbear consists uniformly of dolomite and pseudobrecciated dolomite. The subcrop of the Birdbear is a belt only about 10–20 miles wide except near the Pryor Mountains, where it is as much as 65 miles wide (fig. 2). At the subsurface reference section of the Cottonwood Canyon Member in the Pan American 72 Elk Basin Madison Unit well, which is within this belt, the Birdbear is only 19 feet thick, whereas 22 miles to the southwest, where overlain by the Three Forks Formation at Clarks Fork Canyon, it is 27 feet thick (fig. 1).

A common misconception among some geologists is that the Three Forks Formation extends farther east than is shown in figure 2 and is present in the subsurface at the Elk Basin oil field and elsewhere in the Bighorn Basin, Wyo. This fallacy, which results partly from incorrect placement of the pre-Mississippian unconformity, is repudiated by a comparison of units below the Cottonwood Canyon Member at the subsurface and Clarks Fork Canyon reference sections, which are described later in this report. The so-called Three Forks of subsurface usage is a sequence, 62–69 feet thick, of brownish dolomite interbedded with varicolored shale and siltstone, which supposedly underlies the

Madison Limestone in the Elk Basin field, according to Rea (1962). Correlation from the Pan American 189 Pre-Madison Unit well, where this unit was identified by Rea (1962, fig. 1), to the reference well only 7,000 feet to the southeast clearly demonstrates that there the so-called Three Forks lies directly below the Birdbear Formation, not the Madison Limestone, at a depth of 5,832.2 feet and that it is capped by a bed of greenish-gray dolomitic siltstone. The Birdbear and the underlying siltstone at the reference well are readily correlated with the same two units at the Clarks Fork Canyon section, which was further correlated with a measured section at Logan, Mont., by Sandberg (1967). As the Birdbear is the upper member of the type Jefferson at Logan (Sandberg, 1965), the Three Forks of Rea (1962) must be the upper part of the lower member of the Jefferson or the upper part of the equivalent subsurface Duperow Formation. The true Three Forks, which overlies the Birdbear and as previously mentioned is only 15 feet thick at Clarks Fork Canyon, and the upper 8 feet of the Birdbear are truncated beneath the Cottonwood Canyon Member between Clarks Fork Canyon and the reference well.

The description of cores from the reference well demonstrates the unconformity at the base of the Cottonwood Canyon Member, the deep weathering of underlying beds, and the stratigraphic leak of conodonts downward into the weathered part of the Birdbear. Beneath a sharp contact at a depth of 5,819.2 feet is a regolithic zone, 1.6 feet thick, composed largely of disoriented pebbles of silty dolomite. These pebbles were derived from and grade into an underlying highly weathered zone, 0.8 foot thick. This zone, where the rock is highly fractured but incipient pebbles are oriented and largely in place, is transitional between the regolithic zone above and the weathered zone below. The underlying weathered zone, 9 feet thick, consists of brecciated dolomite that becomes progressively less brecciated downward. Solution crevices, fractures, and vugs in all three zones apparently were open when the Cottonwood Canyon Member was deposited, although they were later sealed by anhydrite. They contain identifiable infiltrations of quartz silt and sand, glauconite grains, fish remains, and conodonts. The effects of weathering are clearly recognizable for about 11.4 feet below the unconformity. A few related hairline fractures without fillings extend downward for an additional 7 feet into largely unweathered dolomite in the basal part of the Birdbear. Conodonts from the Cottonwood Canyon Member are found at a depth as low as 5,825.3 feet, or about 6 feet below the unconformity. Similar infiltrations of conodonts in the top few inches of the Birdbear were noted at Little Dryhead Canyon on the east side of the Pryor Mountains (fig. 2).

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These observations make the authors hesitant to unequivocally accept evidence for dating provided by broken or abraded conodonts in the top of the Sappington Member or in any other units where they directly underlie an unconformity.

Most of the eastern half of the Cottonwood Canyon Member transects a single body of moderately thick cyclically deposited marine carbonate rocks of early Late Devonian (Frasnian) age (fig. 2), to which three names are locally applied. This body of rocks comprises the lower member of the Jefferson Formation in outcrops in Montana and Wyoming, the exactly equivalent Duperow Formation in the subsurface of the same area, and the largely equivalent Darby Formation in the Wind River Basin and adjacent outcrops. The contact with the lower member of the Jefferson is well exposed at the type section of the Cottonwood Canyon Member and at several other measured sections in northern Wyoming (fig. 4, cols. 5–7; Sandberg, 1967).

In the subsurface of central Montana, the Duperow Formation is deeply eroded on the margins of the ancestral Central Montana uplift. In the core of this latest Devonian to earliest Mississippian uplift, the Duperow is truncated and in a narrow belt the Cottonwood Canyon Member rests on the Red River Formation of Late Ordovician age (fig. 2). In a small area at the probable apex of this ancestral uplift, the Cottonwood Canyon unconformably overlies undivided rocks of Late Cambrian and Early Ordovician age. This contact was penetrated at a depth of 8,265 feet in the Texas 1 Manion well on the Ragged Point anticline.

In the southern Bighorn Mountains, the Cottonwood Canyon Member truncates the lower member of the Jefferson Formation and rests successively on the Bighorn Dolomite of Ordovician age and the Gallatin Limestone of Cambrian age (fig. 2). Southeastward from the Bighorn Mountains, small thin discontinuous patches of the Cottonwood Canyon, not shown in figures 1 and 2, rest on progressively older Cambrian rocks in the subsurface of the southern Powder River Basin. In the Hartville Uplift, southeast of the report area, a thin conodont-bearing sandstone related to the Cottonwood Canyon rests with marked angularity on Precambrian schist and gneiss.

COTTONWOOD CANYON MEMBER

GENERAL DISCUSSION

The name Cottonwood Canyon Member is here applied to a thin but complex well-dated sequence of clastic transgressive-marine rocks that lies at or near the base of the Madison Limestone of Mississippian and, locally, Devonian age in Wyoming and at the base of the Lodgepole Limestone of Early Mississippian age in Montana (fig. 3). This

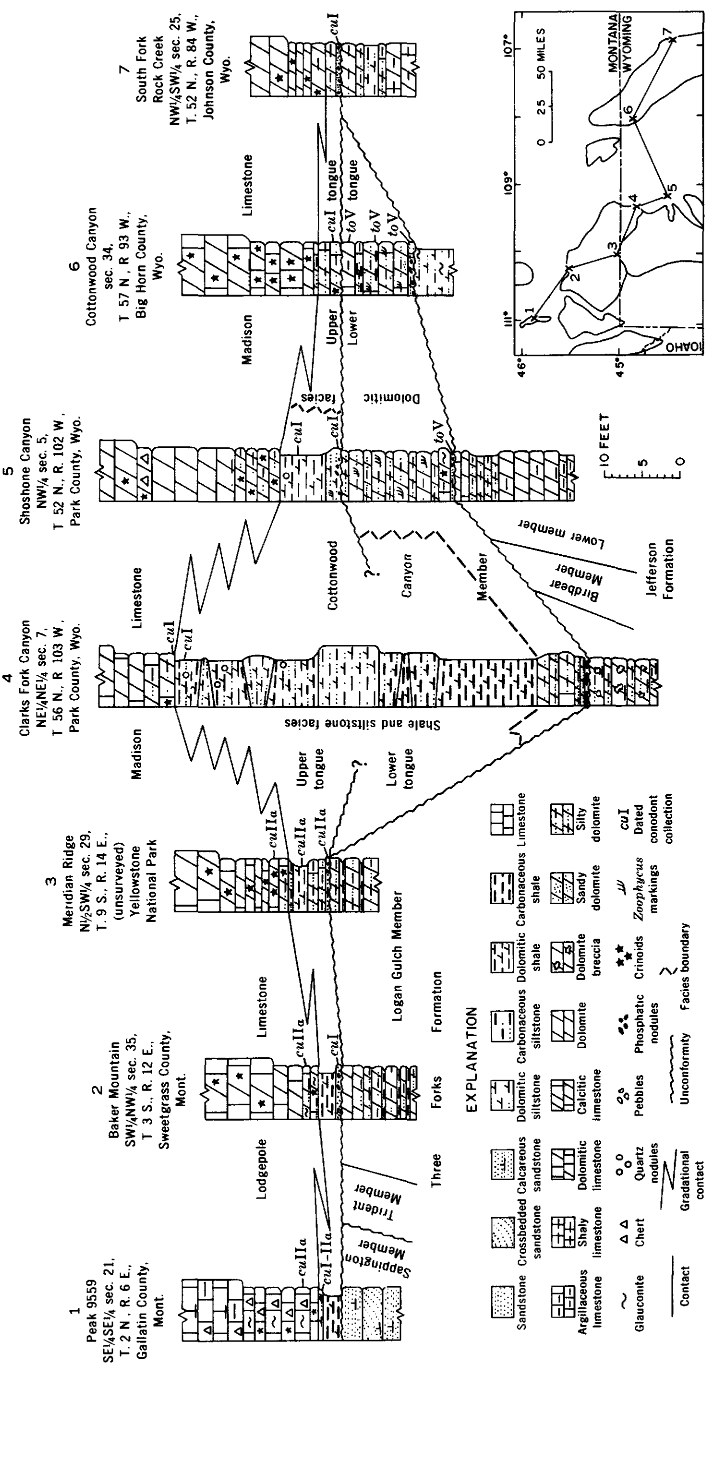

FIGURE 4.—Cross section of Cottonwood Canyon Member and adjacent rocks between Bridger Range, Mont., and Bighorn Mountains, Wyo.

name replaces the informal "dark shale unit of Devonian and Mississippian age," which was proposed by Sandberg (1963) and subsequently used by Sandberg (1965; 1967), Klapper (1966), and Benson (1966). The contact between the Cottonwood Canyon Member and the undifferentiated carbonate rocks in the lower part of the Madison is now recognized to be generally conformable, and is not disconformable as stated by Sandberg (1963). At some localities the contact is gradational or intertonguing (figs. 3, 4). In Montana, the contact between the member and the undifferentiated carbonate rocks in the lower part of the Lodgepole may locally appear to be disconformable because of an abrupt lithologic change.

The Cottonwood Canyon Member is divided into an upper tongue and a lower tongue, both of which have basal conglomeratic lag deposits characterized by abundant phosphatic nodules and coprolites, conodonts, fish remains, and glauconite grains. These tongues are not similarly distributed, but where both tongues are present and can be differentiated, they are separated by a physical disconformity as well as by a hiatus in conodont faunas. The member is also divided areally into a western, shale and siltstone facies and an eastern, dolomitic facies. These facies interfinger, and both may be present within a single tongue at a given locality—for example, Clarks Fork Canyon (fig. 4, col. 4). Consequently, only the eastern limit of the shale and siltstone facies is shown in figure 1.

TYPE SECTION

The Cottonwood Canyon Member is well exposed in the canyon after which it is named on the west side of the northern Bighorn Mountains, 16 miles east of Lovell, in northern Wyoming. The type section is on the north wall of Cottonwood Canyon, about 1 mile east of the mouth, in sec. 34, T. 57 N., R. 93 W., Big Horn County, Wyo., as shown on the Cody 1:250,000 Army Map Service sheet NL 12–12. From Lovell, the canyon is approached in a passenger car by driving 10½ miles east on Wyoming State Highway 14 to the east side of the bridge across the Bighorn River. A wide graded dirt road extends 5½ miles from the north side of the highway to a quarry, which supplied riprap used in constructing the bridge approaches, at the mouth of the canyon. From the canyon mouth, an automobile can be driven for about half a mile on a passable trail through the narrow formed by a cliff of Madison Limestone to a wide part of the canyon, where dipping brown-weathering thick ledges of the Jefferson Formation lie about 100 feet above trail level at a burned grove of cottonwood trees. From this trail the type section is approached on foot by climbing a talus slope across dipping ledges of Jefferson to the base of the high cliff of Madison, about 500 feet above the trail. From there it is necessary to follow the orange-weathering Cottonwood Canyon Member for about three-eighths mile eastward to a point where its contact with the Jefferson is not concealed by talus and the westward dip has decreased to about 20°. Here the type section is well exposed in the base of the cliff of Madison Limestone (fig. 5).

The type section of the Cottonwood Canyon Member comprises both tongues of the member in their dolomitic facies and contains a succession of diagnostic well-preserved conodont faunas. It was selected not only for the excellence of the exposure but also because it demonstrates a well-developed basal lag deposit, a disconformity between

FIGURE 5.—Type section of Cottonwood Canyon Member of Madison Limestone on north wall of Cottonwood Canyon, west side of Bighorn Mountains, Wyo. Member lies between lower member of Jefferson Formation (Djl) and undifferentiated lower part of Madison Limesone (MDm). Numbers (1–8) correspond to numbered units in measured section.

the two tongues, and an almost imperceptible gradation into overlying beds of the Madison Limestone, as described in the following measured section.

Type section of the Cottonwood Canyon Member of the Madison Limestone at Cottonwood Canyon in sec. 34, T. 57 N., R. 93 W., Big Horn County, Wyo.

[First number in parentheses is Ca:Mg molal ratio; second number is percentage of total carbonate by weight]

	Thickness (ft)
Madison Limestone:	
Undifferentiated lower part:	
8. Dolomite, calcitic, (1.36, 90), light-gray, yellowish-gray, and very pale yellowish brown, microcrystalline, microsucrosic, finely to coarsely fossil-fragmental, crinoidal, slightly silty. Contains crinoid columnals and leached fossil molds, mostly of crinoids. Weathers to yellowish-gray rough, pitted surface; massive; resistant; cliff forming	21+
7. Limestone, dolomitic, (8.62, 93), medium-light-gray, medium-gray, and light-olive-gray, microcrystalline, finely to coarsely fossil-fragmental, crinoidal. Grades laterally to calcitic dolomite. Contains Kinderhook (*cu*I–IIα) conodont fauna and *Syringopora* sp. and *Vesiculophyllum* sp. corals in lower 3 ft. Weathers medium gray; medium to thick bedded; resistant; forms 3 slightly reentrant ledges	7
6. Dolomite, calcitic, (2.25, 89), medium-gray, medium-light-gray, and light-olive-gray, microcrystalline, very finely to finely fossil-fragmental, slightly silty. Bottom 2 in. is slightly hematitic silty calcitic dolomite (1.72, 77). Unit contains scattered crinoid columnals, small brachiopods, and Kinderhook conodonts. Weathers medium gray; thin to medium bedded; moderately resistant; forms 2 reentrant ledges	2
Total described undifferentiated lower part of Madison Limestone	30+
Gradational contact.	
Cottonwood Canyon Member:	
5. Dolomite, calcitic, silty, (1.46, 84), yellowish-gray and light-olive-gray mottled with yellowish-orange, microcrystalline, microsucrosic, slightly argillaceous, containing scattered limonite nodules and leached fossil molds mostly of crinoids. Contains Lower Carboniferous (upper *cu*I) conodont fauna throughout. Weathers to yellowish-gray and pale-yellowish-orange minutely pitted surface; thin to medium bedded; moderately resistant; forms reentrant ledge.	3
Disconformity.	
4. Dolomite, calcitic, (1.29, 90), grayish-orange to pale-yellowish-brown and medium-light-gray to light-olive-gray, very finely crystalline, rhombic, sucrosic, vuggy, slightly sandy, slightly silty, slightly limonitic. Silt is subangular grains of quartz, slightly smaller than very fine grained sand. Sand is fine to medium rounded frosted grains of quartz. Contains fish fragments and very late Devonian (upper *to*V) conodont fauna in lower 1 ft. Weathers to grayish-orange, yellowish-orange, and light-yellowish-brown pitted surface; medium bedded; moderately resistant; forms reentrant ledge	2

Type section of the Cottonwood Canyon Member of the Madison Limestone at Cottonwood Canyon—Continued

	Thickness (ft)
Madison Limestone—Continued	
Cottonwood Canyon Member—Continued	
3. Dolomite, calcitic, silty (1.28–1.75, 72–77), grayish-orange, dark-yellowish-orange, yellowish-orange, pale- to moderate-yellowish-brown, and medium-light-gray, very finely crystalline, rhombic, sucrosic, limonitic, slightly sandy, containing wisps and laminae of dark-gray to black carbonaceous dolomitic quartzose shale and nodules of limonite. Silt is subangular grains of quartz, slightly smaller than very fine grained sand. Sand is fine to coarse rounded frosted grains of quartz. Fucoids and *Zoophycus* markings on bedding planes. In 3 ledges. 1-in.-thick reentrant at top and two 2-in.-thick reentrants that separate ledges are black and mottled greenish-gray, yellowish-gray, and dark-gray carbonaceous dolomitic quartzose shale (1.10, 26). Dolomite ledges contain abundant conodonts and fish fragments. Shale interbeds also contain conodonts, which were determined to be very late Devonian (upper *to*V) by Ethington, Furnish, and Wingert (1961). Dolomite weathers to dark-yellowish-orange smooth surfaces except upper 1-ft-thick ledge which weathers yellowish orange; shale weathers yellowish gray; thin to medium bedded; moderately resistant; ledge forming	7
2. Dolomite, calcitic, very silty, very sandy, conglomeratic (1.44, 58),[4] pale-yellowish-brown, grayish-orange, medium-gray, and medium-dark-gray, grading to subangular to subrounded very fine grained very dolomitic siltstone and sandstone. Contains laminae of black carbonaceous dolomitic quartzose shale, granules and rounded pebbles of yellowish-gray and greenish-gray microcrystalline silty dolomite, fine to coarse rounded frosted grains of quartz, and limonitic and phosphatic nodules. Also contains abundant very late Devonian (upper *to*V) conodont fauna and fish bones, plates, teeth, and scales. Weathers light brown and dark yellowish orange; medium bedded; moderately resistant; forms ledge at base of cliff	1
Total Cottonwood Canyon Member	13
Unconformity.	
Jefferson Formation:	
Upper part of lower member:	
1. Siltstone, very dolomitic, (1.12, 40), light-greenish-gray, greenish-gray, and grayish-yellow-green, glauconitic; partly sandy. Weathers yellowish gray; thin bedded to thinly laminated; nonresistant; slope forming	26

[4] High Ca:Mg molal ratio is attributed to excess calcium, largely from fluorapatite and collophane and due to presence of 4–6 percent by weight of conodonts, fish remains, and phosphatic nodules. Reanalysis of same powdered sample after removal of clay-size fines by washing and of conodonts and other phosphatic grains by heavy liquid and magnetic separation techniques: (1.26, 74).

REFERENCE SECTIONS

The reference section for the shale and siltstone facies of the Cottonwood Canyon Member is in the Beartooth Mountains at Clarks Fork Canyon, north of the river in the NE¼NE¼ sec. 7, T. 56 N., R. 103 W., Park County, Wyo., in the Deep Lake 15-minute quadrangle. This section (fig. 4, col. 4) was formerly considered the reference section of the dark shale unit. As a detailed stratigraphic section and complete directions for visiting this locality were given by Sandberg (1963, p. 17), they are not repeated here. It should be noted, however, that the 48 feet of beds previously assigned to the dark shale unit is now assigned to the shale and siltstone facies there. An underlying sequence of silty dolomite 7 feet thick is now recognized to be included in the Cottonwood Canyon and is assigned to the dolomitic facies. Consequently, the member has a total thickness of 55 feet at this reference section. As a detailed description of the added part of the member was not given by Sandberg (1963), it is presented here; descriptions of three thin underlying units—the Logan Gulch Member of the Three Forks Formation, the Birdbear Member of the Jefferson Formation, and the top bed of the lower member of the Jefferson Formation—are given for comparison with their descriptions at the subsurface reference section.

Measured section of the dolomitic facies of the Cottonwood Canyon Member of the Madison Limestone and adjacent units at Clarks Fork Canyon

[Section measured in NE¼NE¼ sec. 7, T. 56 N., R. 103 W., Park County, Wyo. First number in parentheses is Ca: Mg molal ratio; second number is percentage of total carbonate by weight]

	Thickness (ft)
Madison Limestone:	
Cottonwood Canyon Member:	
Shale and siltstone facies (described by Sandberg, 1963, p. C17)	48
Dolomitic facies:	
Dolomite, silty, calcitic (1.52, 78), microcrystalline; dark yellowish orange in upper part, medium gray mottled with dark yellowish orange in lower part. Weathers to yellowish-orange smooth surface with 1- to 2-in.-wide pits formed by weathering of calcite geodes; thick bedded; moderately resistant; ledge forming	5
Dolomite, silty (1.16, 63), brownish-gray to medium-dark-gray and yellowish-gray, microcrystalline. Lower 6 in. is medium-dark-gray very dolomitic quartzose shale (1.08, 46). Black carbonaceous films on bedding planes resemble macerated plant or algae remains. Weathers yellowish gray and medium gray; platy; weakly resistant; forms reentrant	2
Total dolomitic facies	7
Total Cottonwood Canyon Member	55

Measured section of the dolomitic facies of the Cottonwood Canyon Member of the Madison Limestone and adjacent units at Clarks Fork Canyon—Continued

	Thickness (ft)
Unconformity.	
Three Forks Formation:	
Logan Gulch Member:	
Dolomite, silty (1.07, 65), mottled yellowish-gray, light-olive-gray, light-brown, and greenish-gray, microcrystalline. Grades to silty dolomite evaporite-solution breccia (1.12, 64) containing angular fragments and flakes of light-greenish-gray dolomitic shale. Weathers to yellowish-gray and dark-yellowish-orange rough surfaces; in beds ½- to 4-in. thick; moderately resistant; ledge forming	11
Dolomite, calcitic, silty (1.54, 87), yellowish-orange, yellowish-gray, and light-brown with grayish-red hematitic laminae, very finely crystalline, fragmental, limonitic; partly nodular. Contains interbeds and scattered angular fragments of light-greenish-gray dolomitic shale. Weathers yellowish gray and moderate yellowish brown; thin bedded to laminated; cross-bedded; ripple marked; moderately resistant; ledge forming	4
Total Three Forks Formation	15
Jefferson Formation:	
Birdbear Member:	
Dolomite, calcitic (1.37, 96), pseudobrecciated, yellowish-orange, yellowish-gray mottled with light-gray, light-brownish-gray, and medium-light-gray, very finely crystalline, rhombic, sucrosic, porous. Stained by limonite and hematite. Fractures and vugs filled with white calcite. Weathers to mottled moderate-yellowish-brown and yellowish-gray rough pitted surface; massive; resistant; cliff forming	27
Total Birdbear Member	27
Lower member:	
Shale, quartzose, dolomitic light-olive-gray, yellowish-gray, and dusky-yellow, glauconitic. Interlaminated with light-gray to greenish-gray clay shale. Bottom 4 ft contains a few 1-ft-thick interbeds of dark-yellowish-orange silty dolomite. Weathers yellowish gray and dusky yellow; weakly resistant; slope forming	13

The subsurface reference section of the Cottonwood Canyon Member is here designated the interval between core depths of 5,806.9 and 5,819.2 feet in the Pan American 72 Elk Basin Madison Unit well of the Elk Basin oil field in the northwestern Bighorn Basin (fig. 1). This well is in the NW¼SE¼ sec. 30, T. 58 N., R. 99 W., Park County, Wyo. The thickness of the Cottonwood Canyon Member, on the basis of cores, is 12.3 feet. Adjustment to the gamma-ray log locates the member between well depths of 5,807 and 5,820 feet and gives it an apparent thickness of 13 feet. After this thickness is corrected for a dip of 30° and a borehole deviation of 11° from vertical in the direction of dip, the true stratigraphic thickness rounded to the nearest foot is 12 feet. The subsurface reference section of the member is within the dolomitic facies of its upper tongue. The eastern limit of the shale and siltstone facies is projected to lie about 10 miles west of the well (fig. 1). Detailed lithologic descriptions of the cored interval between 5,798.4 and 5,846.5 feet from the lower part of the Madison Limestone to the upper part of the Duperow Formation, about 4½ feet above the bottom of the well, are presented. They demonstrate not only the upward gradation of the Cottonwood Canyon into the overlying part of the Madison but also the previously discussed basal unconformity and deep weathering of underlying beds.

Subsurface reference section of the Cottonwood Canyon Member of the Madison Limestone

[Section described from cores of the Pan American Petroleum 72 Elk Basin Madison Unit well, NW¼SE¼ sec. 30, T. 58 N., R. 99 W., Park County, Wyo. Numbers in parentheses are core depths, in feet]

	Thickness (ft)
Mississippian:	
Madison Limestone:	
Undifferentiated lower part:	
Dolomite, light-olive-gray, finely microcrystalline, crinoidal. Contains conodonts and yellowish-gray ghosts of crinoids and other fossil debris, 1–2 mm in diameter (5,798.4–5,800.4)	2.0
Dolomite, medium-gray, microcrystalline, microsucrosic, very slightly pyritic (5,800.4–5,801.6)	1.2
Dolomite, light-olive-gray and mottled medium-gray and medium-light-gray, microcrystalline, slightly anhydritic; partly cherty; partly slightly pyritic and slightly glauconitic. Contains crinoids and fish fragments. White cryptocrystalline chert nodules, as much as 11 mm in diameter, at 5,803.0–5,803.5 ft (5,801.6–5,804.9)	3.3
Dolomite, medium-light-gray to light-olive-gray, microcrystalline, slightly anhydritic, containing scattered conodonts and a few minute fish fragments. Wisps and laminae of medium-gray and brownish-black slightly hematitic, silty, and shaly coarsely microcrystalline dolomite in upper and lower parts and slight grayish-red and grayish-red-purple speckling and streaking in middle. Parting of light-greenish-gray silty shale at 5,805.4 (5,804.9–5,805.9)	1.0
Dolomite, light-olive-gray, microcrystalline, sucrosic, slightly anhydritic, containing scattered fragmentary conodonts and fish teeth. A few scattered hematite and quartz silt grains in bottom 0.2 ft (5,805.9–5,806.9)	1.0
Total described undifferentiated lower part of Madison Limestone	8.5
Gradational contact.	

Subsurface reference section of the Cottonwood Canyon Member of the Madison Limestone—Continued

	Thickness (ft)
Mississippian—Continued	
Madison Limestone—Continued	
Cottonwood Canyon Member:	
Dolomite, light-brownish-gray, mottled and streaked with pale-red, grayish-red-purple, dusky-red-purple, and grayish-red, coarsely microcrystalline, hematitic, slightly silty and slightly anhydritic; partly slightly crinoidal and medium fossil-fragmental. Contains scattered fragmentary conodonts and fish teeth (5,806.9–5,809.2)	2.3
Dolomite, silty, light-brownish-gray, mottled, streaked, and banded with pale-red, grayish-red, grayish-red-purple, and dusky-red, coarsely microcrystalline to microcrystalline, hematitic, slightly anhydritic. Contains scattered conodonts. Interbed, ¼ in. thick, of thinly laminated very silty dolomite at 5,810.5 (5,809.2–5,813.0)	3.8
Dolomite, silty to very silty, mottled and irregularly banded light-brownish-gray, pale-red, grayish-red, and grayish-red-purple, microcrystalline, laminated. Contains scattered conodonts, fish remains, and small black phosphatic nodules. Thin interbeds, laminae, and lenses of very dolomitic siltstone. Round nodules of white chert, in part fragmental, at 5,813.0–5,813.4 (5,813.0–5,815.0)	2.0
Siltstone, very dolomitic, light-brownish-gray mottled and irregularly banded with pale-red, grayish-red, and grayish-red-purple, hematitic; in part slightly glauconitic; laminated. Grades to coarsely microcrystalline to very finely crystalline very silty dolomite. Contains black phosphatic nodules, as much as 1 in. long, at 5,816.2–5,816.3. Bottom 0.1 ft is thinly laminated friable dolomitic siltstone (5,815.0–5,816.8)	1.8
Dolomite, very silty, grayish-red-purple and medium-light gray, microcrystalline, hematitic, containing unoxidized light-olive-gray slightly glauconitic mottles. Bottom 0.1 ft is laminated (5,816.8–5,817.2)	.4
Siltstone, very dolomitic, greenish-gray, slightly glauconitic (5,817.2–5,817.5)	.3
Siltstone, very dolomitic, light-brownish-gray and light-olive-gray mottled with pale-red and grayish-red-purple, hematitic, slightly glauconitic; quartzitic in bottom 0.2 ft. Gradational to very silty dolomite, with some dolomite replacing abundant quartz grains and sparse feldspar grains. Contains scattered glauconite grains, small black phosphatic nodules, fish teeth, fragmentary fish plates, vertical worm burrows, and conodonts, which are most abundant in bottom 0.5 ft (5,817.5–5,819.0)	1.5

Subsurface reference section of the Cottonwood Canyon Member of the Madison Limestone—Continued

	Thickness (ft)
Mississippian—Continued	
Madison Limestone—Continued	
Cottonwood Canyon Member—Continued	
Sandstone, quartzitic, arkosic, dolomitic, yellowish-gray, medium- to coarse-grained, well-rounded. Quartz and feldspar grains partly replaced by dolomite. Contains interbeds and lenses of grayish-yellow-green highly glauconitic, grayish-red hematitic, and dark-gray carbonaceous dolomitic quartzose shale. Abundant large conodonts and fish bones, as long as ¼ in., in shale at top. Overlies a sharp, wavy surface (5,819.0–5,819.2)	.2
Total Cottonwood Canyon Member	12.3
Unconformity.	
Devonian:	
Birdbear Formation:	
Dolomite conglomerate, regolithic, grayish-red mottled with pale-red, hematitic. Subordinate groundmass is grayish-red dolomitic quartzose shale. Predominant pebbles, which increase in abundance downward, are pale-red very finely crystalline rhombic sucrosic silty dolomite. Grades into underlying unit at horizon where pebbles become groundmass. Abundant cracks are filled with sand and silt grains that infiltrated from above unconformity. Pod, at least ⅜ in. long, at 5,819.7 is medium-grained sandstone, identical with that overlying unconformity (5,819.2–5,820.8)	1.6
Dolomite, silty, very finely crystalline, pale-red mottled with moderate-red, grading downward through grayish-orange-pink to pale-yellowish-brown. Irregular crevices, cracks, veinlets and seams filled by infiltrations of grayish-green dolomitic shale and light-olive-gray dolomitic siltstone containing inclusions of sandstone, fish remains, glauconite grains, and conodonts. Unit represents highly weathered zone that contributed to overlying regolith (5,820.8–5,821.6)	.8
Dolomite, brecciated, pale-yellowish-brown, coarsely microcrystalline to very finely crystalline, sucrosic; massive; locally pseudobrecciated; partly mottled pale red and more locally grayish red by secondary hematite staining. Contains abundant fractures, sealed by anhydrite, that connect large vugs completely filled with white coarsely crystalline secondary anhydrite. Grayish-red halos in dolomite surround anhydrite-filled vugs. Infiltrations of greenish-gray shale, light-olive-gray siltstone, and quartz and glauconite grains are common in sealed fractures and on edges of anhydrite-filled vugs at 5,821.6–5,825.3 ft; below that only traces exist. Unit represents slightly weathered zone that grades into underlying unit (5,821.6–5,830.6)	9.0
Dolomite, pale-yellowish-brown, very finely crystalline to coarsely microcrystalline. Contains a few fractures, stylolites, and anhydrite-filled vugs (5,830.6–5,834.0)	3.4

Subsurface reference section of the Cottonwood Canyon Member of the Madison Limestone—Continued

	Thickness (ft)
Devonian—Continued	
Birdbear Formation—Continued	
Dolomite, yellowish-brown, dark-yellowish-brown, and brownish-gray, microcrystalline, microsucrosic. Contains a few fractures, stylolites, and anhydrite-filled vugs (5,834.0–5,837.6)	3. 6
Dolomite, silty to very silty, pale-brown and pale-, moderate-, and dark-reddish-brown, hematitic; thin bedded to laminated. Contains broken laminae of pale-red dolomitic siltstone and a few mottles of unoxidized grayish-yellow-green glauconitic silty dolomite (5,837. 6–5, 838.2)	. 6
Total Birdbear Formation	19. 0
Conformable contact.	
Duperow Formation:	
Siltstone, dolomitic, greenish-gray, light-olive-gray, and yellowish-gray, glauconitic; in part laminated; in part stained pale red and dusky red by hematite. Contains thin interbeds and laminae of greenish-gray dolomitic quartzose shale and clay shale (5,838. 2–5,846. 5)	8. 3

DISTRIBUTION AND THICKNESS

The Cottonwood Canyon Member is largely continuous in an area of about 50,000 square miles in central, south-central, and southwestern Montana and in north-central, northwestern, and west-central Wyoming (fig. 1). It crops out in all the moutain ranges included within the limits shown in figures 1 and 2, except in the Crazy Mountains, Mont., where Paleozoic rocks are not exposed. It is also present in the subsurface of intervening and adjacent areas. The Cottonwood Canyon has been sampled and described at about 50 measured sections and recognized in sample and radioactivity logs of about a hundred wells. Thin isolated patches of the member or of related lag deposits at the base of the Lodgepole and Madison Limestones occur northwest, east, and southeast of the limits of the main body of the Cottonwood Canyon, but they are too small or too poorly delimited to be shown in figures 1 and 2.

Probable outliers of the shale and siltstone facies of the Cottonwood Canyon Member are recognized in the vicinity of the Big and Little Belt Mountains, Mont. (fig. 2). At Beaver Creek in the Big Belt Mountains, a black shale 20 inches thick, with a basal conodont-rich lag sandstone half an inch thick, underlies the Lodgepole Limestone and overlies unit 5 of the Sappington Member of the Three Forks Formation. At Bandbox Mountain and Grendah Mountain in the Little Belt Mountains, a ½-inch-thick conodont-rich lag siltstone at the base of the Lodgepole overlies unit 2 of the Sappington. Similar deposits are recognized at the base of the Lodgepole in the subsurface about 20 miles northwest of Lewistown, Mont. (fig. 1).

The eastern limit of the Cottonwood Canyon Member, which is also the limit of its dolomitic facies, is only approximately located in figure 1 because of a paucity of control wells in the Powder River Basin. Thin beds clearly related to the dolomitic facies are recognized beyond this approximate limit, however. At the Shell Oil 1 Clear Creek well, 38 miles east of Sheridan, Wyo. (fig. 1), the basal 7 feet of the Madison Limestone is silty dolomite that is lithologically similar to the Cottonwood Canyon Member (Sandberg, 1967). Likewise, at four wells, not shown in figure 1, in the southeast corner of the report area and just to the south, silty or sandy dolomite in the basal 3–15 feet of the Madison rests on Cambrian rocks. At Ragan Draw in the Hartville Uplift of east-central Wyoming, a conodont-bearing sandstone 3 feet thick, described by Sandberg (1967), at the base of the lower part of the Guernsey Formation of Devonian and Mississippian age rests on Precambrian rocks and may be connected to both the Cottonwood Canyon Member and the equivalent Devonian and Mississippian Englewood Formation of the Black Hills (Sandberg, 1963).

The Cottonwood Canyon Member ranges in thickness from 0 to about 80 feet in the report area. It probably is as much as 90–100 feet thick in the subsurface of the Green River Basin, just east of the Wyoming Range and south of the western part of the report area (fig. 1). At most measured sections it is less than 10 feet thick, but at four sections it is 10–20 feet thick and at eight sections it is more than 20 feet thick. The member is thicker than 20 feet in an elongate belt whose width ranges from 12 to 65 miles and averages 35 miles (fig. 1). The axis of this belt of thicker accumulation trends N. 15°–20° E. from the west side of the Green River Basin, past the north end of the Wind River Range, to the south side of the eastward-trending Central Montana uplift near Roundup, Mont. (fig. 1). There, the axis bends sharply eastward and trends N. 75° E. to its eastern termination at Porcupine dome, on the east end of the uplift. Two centers of deposition lie within this belt: one is in the subsurface south of Roundup, where the member is about 70 feet thick; the other is in the western Washakie Range, Wyo., where the member is about 80 feet thick. Eastward and westward thinning from the narrow apparent basin of thicker accumulation to adjacent wide shelf areas of thinner accumulation takes place in such short distances, as shown in figure 4, that only a few critical isopachs within the transition zone could be shown in figure 1. The member is 55 feet thick at Clarks Fork Canyon, but it thins northeastward in 22 miles to a thickness of 12 feet at the subsurface reference section. It maintains a relatively constant thickness for 40 miles eastward from there to the type section, where it is 13 feet thick. Abrupt thinning is further demonstrated by closely spaced measured sections in the Washakie Range (fig. 1), where the member thins eastward from about 80 to 4 feet in a distance of about 20 miles.

LITHOLOGIC AND PHYSICAL CHARACTER

The Cottonwood Canyon Member in its dolomitic facies, as exemplified by the type and Shoshone Canyon sections (fig. 4, cols. 5, 6), is largely very finely crystalline to microcrystalline slightly calcitic silty dolomite that is platy to medium bedded, light colored, limonitic, glauconitic, and slightly hematitic. The fresh rock surfaces are most commonly yellowish gray, yellowish orange, grayish orange, light gray, medium light gray, light olive gray, light greenish gray, pale red, light brownish gray, and pale yellowish brown. The silty dolomite generally weathers to yellowish-gray smooth surfaces, but where the silt content is high to moderate it weathers dark yellowish orange at the base and grades to yellowish orange and grayish orange at the top. The silty dolomite contains scattered to abundant very fine to very coarse rounded frosted quartz sand grains, fine to very fine glauconite grains, limonitic (probably originally sideritic) nodules, and phosphatic nodules and coprolites. Thin interbeds, lenses, and wisps of medium-dark-gray to black carbonaceous dolomitic quartzose shale are present at some localities. Conodonts, fish remains, and *Zoophycus* (*Taonurus*, *Spirophyton*) markings are common, and fucoids, crinoid columnals, and *Syringopora* sp. corals occur locally. The corals have been observed only where the silt content is relatively low.

In outcrop, the dolomitic facies generally forms the base of a cliff of Madison Limestone (fig. 5), or slightly reentrant ledges just below. However, where the facies is very thin it may form only a reentrant. The dolomitic facies has been mapped, depending on its thickness and the local topography, with the Madison (Hose, 1955, p. 48–49) or with an unconformably underlying weakly resistant unit (Murphy and Richmond, 1965). In the subsurface this facies may be difficult to differentiate from overlying beds of the Madison except by close scrutiny of well cuttings. It is easily recognized in cores, however, and is generally expressed on radioactivity well logs by a moderate to slight deflection of the gamma-ray curve to the right.

The Cottonwood Canyon Member in its shale and siltstone facies, as characterized by the Clarks Fork Canyon reference section (fig. 4, col. 4; Sandberg, 1963), is dark-gray to black and greenish-gray carbonaceous dolomitic quartzose shale and mudstone interbedded with medium-colored—moderate yellowish brown, dark yellowish orange, and medium dark gray partly banded or mottled with light olive gray and yellowish gray—limonitic glauconitic carbonaceous dolomitic siltstone, grading to very silty dolomite. A sample of carbonaceous shale from the Hunter Peak locality in the northern Absaroka Range, between Clarks Fork Canyon and Meridian Ridge (fig. 1), yielded 10.3 gallons of oil per ton on pyrolysis by the Ruska Still method (R. F. Gantnier, written commun., 1959). The shale weathers dark to medium gray and light olive gray; the dolomitic siltstone weathers yellowish brown, dark yellowish orange, light brown, and yellowish gray. Botryoidal nodules or geodes ½–1 inch in diameter of white crystalline quartz with vugs and cracks partly filled with calcite, hematie, or pyrite are locally present in the shale (fig. 4, cols. 4, 5). The siltstone contains glauconite grains, limonitic (sideritic?) nodules, *Zoophycus* markings, and carbonaceous films and wisps. Scattered conodonts, fish remains, phosphatic nodules and coprolites, and, less commonly, crinoid columnals occur in both the shale and siltstone. The shale also contains abundant marine palynomorphs including hystricosphaeres, *Leiosphaeridia* sp. cysts, *Tasmanites*, and *Micrhystridium* (R. H. Tschudy, written commun., 1962), and linguloid brachiopods and, locally, fenestrate bryozoans and conularids.

In outcrop, the shale and siltstone facies commonly forms a reentrant, a slope, or moderately resistant ledges below a cliff or ledges of carbonate rocks of the Madison or Lodgepole Limestone. In areas of steep topography where the facies is thick, as in the Absaroka Range and southern Beartooth Mountains of Wyoming, however, it may form the base of a cliff of Madison Limestone. Recently, in neighboring quadrangles, the shale and siltstone facies has been mapped at the base of the Lodgepole Limestone (McMannis and Chadwick, 1964; Skipp and Peterson, 1965) or, alternatively, at the top of a poorly exposed underlying unit (Roberts, 1964). In the subsurface, this facies is readily identifiable in both well cores and cuttings and is expressed on radioactivity well logs by a moderate to very sharp deflection of the gamma-ray curve to the right.

The most diagnostic criterion for recognizing the Cottonwood Canyon Member in outcrop is the widespread occurrence of condensed or lag deposits formed by conglomeratic sandstone, quartzite, siltstone, or silty dolomite at the base of one or both tongues of the member regardless of their facies. Even though these deposits probably were not laid down originally as continuous sheets, preservation is so common that at least one such deposit has been recognized to be discontinuously present at every section examined by the authors. Moreover, a

½-inch-thick conodont-rich lag deposit commonly may be found at the base of the Lodgepole or Madison Limestone even where there is no vestige of the upper part of the Cottonwood Canyon Member, as at Bandbox Mountain and Grendah Mountain.

The lithologic character of the transgressive lag (or condensed) deposits of the Cottonwood Canyon Member is recognizably different from that of any other middle or lower Paleozoic rocks in the report area. In gross features and in persistence, however, these deposits are very similar to other condensed deposits, as recognized by Goldman (1922), discussed by Twenhofel (1936), and recently described by McGugan (1965). The lag deposits of the Cottonwood Canyon range in thickness from a fraction of an inch to about 1 foot. They are characterized by abundant conodonts; fish plates, teeth, bones, and scales; glauconite grains; phosphatic coprolites, nodules, and pellets; large quartz sand grains and granules; and granules, pebbles, and cobbles derived from underlying rocks. Some of the conodonts are very large, especially at Baker Mountain, Mont. (fig. 1), where a specimen of reworked *Palmatolepis* measured more than 5½ mm in length. The most common types of fish teeth are *Helodus*, *Cladodus*, and *Orodus*. Phosphatic nodules and coprolites as much as 1 inch in diameter are present at widely spaced localities such as North Crazy Woman Canyon, Baker Mountain, and Horse Creek, a locality 5 miles northwest of Windy Gap (fig. 1). Many of the coprolites incorporate partly digested fish remains and conodonts. Fish bones as much as 4 inches long are present at the base of the lag deposit at South Fork Rock Creek (fig. 4, col. 7). Broken plates of underlying rocks as much as 8 inches long and 1 inch thick are found in the lower part of the lag deposit at Bull Lake Canyon (fig. 1).

The total phosphate content of lag deposits of the Cottonwood Canyon Member may be moderately high as suggested by the following two examples. At Baker Mountain, Mont. (fig. 1), a lenticular quartzitic phosphatic sandstone, 0–4 inches thick, at the base of the shale and siltstone facies grades erratically to dark-gray sandy phosphorite composed largely of conodonts, phosphatic pebbles, and fish plates, bones, and teeth. Semiquantitative determination of this phosphorite by the Shapiro (1952) method indicates a phosphate content of 10–15 percent P_2O_5. In the type section, the lag deposit (unit 2) at the base of the dolomitic facies contains 4–6 percent by weight phosphate largely in the form of conodonts. Although not as phosphatic as the deposit at Baker Mountain, the lag deposit at Cottonwood Canyon contains enough fluorapatite and collophane that the excess calcium from these calcium-phosphate sources exaggerates the apparent Ca:Mg molal ratio of the rock from 1.26 to 1.44, as determined

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by chemical analyses of powdered rock samples without and with the phosphatic material.

FACIES AND FACIES RELATIONS

The Cottonwood Canyon Member is divisible areally into two facies—a western, shale and siltstone facies and an eastern, dolomitic facies (fig. 4). The shale and siltstone facies predominates in the apparent basin of maximum accumulation and occupies the entire shelf area of thin accumulation on the west. Its eastern limit is shown in figure 1. The dolomitic facies is largely within the more extensive shelf area on the east, but it extends slightly into the area of maximum accumulation (fig. 4, col. 4). Its eastern limit is approximately located in figure 1. The general lithologic and physical characteristics of rocks in both facies have already been discussed.

The extremes of the two facies, as illustrated by the most distant columns on the cross section (fig. 4, cols. 1, 7), appear to differ so greatly in lithologic character and resistance to weathering that their correlation might be difficult to prove without additional stratigraphic and paleontologic evidence. At some intervening sections, however, such complete lithologic gradations exist that the separation of the two facies as well as their differentiation from the Madison and Lodgepole Limestones is actually considered to be somewhat arbitrary. Furthermore, some depositional features, which are shared by both facies and by overlying undifferentiated beds in the lower part of the Lodgepole and Madison, help demonstrate the intertonguing and gradational relations between all these units.

The easternmost measured sections of the dolomitic facies of the Cottonwood Canyon Member are at South Fork Rock Creek (fig. 4, col. 7) and at North Crazy Woman Canyon in the eastern Bighorn Mountains, Wyo. (fig. 1). There, the member is largely light-greenish-gray, yellowish-gray, pinkish-gray, and very light gray silty to slightly silty dolomite that grades upward to similarly light-colored but nonsilty dolomite through a 5-foot-thick transition zone in the overlying part of the Madison Limestone. At these localities and at Shell Canyon (fig. 1), the member can be differentiated from overlying beds of the Madison by its visibly higher content of clastic material, hematite, and conodonts.

A little farther west at its type section, the Cottonwood Canyon Member grades upward almost imperceptibly into overlying beds of the Madison Limestone. This gradual transition begins directly above the basal lag deposit (unit 2 of the measured section) and continues upward through a 14-foot-thick zone (units 3–6) that includes the upper 12 feet of the member. The contact between the member and the undifferentiated part of the Madison was selected at the base of unit 6 (fig. 5) only after careful consideration of the diagnostic characteristics of all the other beds within this transition zone. Unit 6 contains scattered crinoid columnals, as does unit 5 at the top of the Cottonwood Canyon; but unlike unit 5 or any of the other underlying units, it weathers medium gray and more closely resembles carbonate rock in the undifferentiated part of the Madison at localities where the contact is sharp and unequivocal.

The gradational contact at the top of the Cottonwood Canyon Member at its type section could have been placed as much as 6 feet lower or 2 feet higher if only one of the several criteria that are useful in differentiating the member elsewhere had been employed. For example, if the characteristic color of weathered surfaces were used, the top of the Cottonwood Canyon could have been placed at a conspicuous color break at the base of a bed 1 foot below the top of unit 3 (fig. 5) and only 7 feet above the base of the member. Below this break the predominant weathering color is dark yellowish orange; above the break the weathering colors are largely yellowish gray, yellowish orange, and grayish orange. If the normally reliable silt content were used as the sole criterion, the contact could have been placed at the base of unit 4, or 8 feet above the base of the member. Unit 4 is a calcitic dolomite that contains about 10 percent silt and 90 percent carbonate, which is the average content of beds at the base of the undifferentiated part of the Madison elsewhere and is the same content as that of the massive beds of unit 8 here. Beds below unit 4 are silty calcitic dolomite that contains a maximum of 77 percent carbonate. However, the overlying unit (5) reverses the trend of an upward decrease in silt content within the member; it is silty calcitic dolomite containing 84 percent carbonate, which is intermediate between the content of units 3 and 4. If bedding thickness alone were used, then the contact could have been placed at the base of unit 7, or 2 feet above the present top of the member, because the beds above this horizon are medium bedded to massive whereas those below are thin to medium bedded (fig. 5). It is apparent, therefore, that the Cottonwood Canyon may grade into the undifferentiated lower part of the Madison through a thick transition zone and that all the physical and lithologic characteristics must be considered in selecting a contact at some localities.

Sections at Peak 9559 and at Baker Mountain (fig. 4, cols. 1, 2) are characteristic of the westernmost outcrops of the shale and siltstone facies in southwestern Montana (fig. 1). At Baker Mountain, the member consists mostly of dark-gray carbonaceous quartzose shale with the previously mentioned quartzitic sandstone and sandy phosphorite at the base. At Peak 9559 as well as throughout the Bridger and Gallatin Ranges and in the vicinity of Logan, Mont., the member is capped by a persistent bed of carbonaceous dolomitic siltstone, about 9 inches thick, that generally displays *Zoophycus* markings.

The shale and siltstone of these westernmost sections form a deep reentrant, and the lithologic change to overlying limestone in the lower part of the Lodgepole Limestone is so abrupt that the contact appears to be a disconformity. However, when the overlying 5–10 feet of beds of the Lodgepole is analyzed, it is found to possess several constituents in common with the Cottonwood Canyon Member: crinoid columnals, highly abundant conodonts, abundant glauconite grains, and stringers and interbeds of carbonaceous shale. Interbeds of shale in the lower part of the Lodgepole locally may be thick. At Bandbox Mountain (fig. 1), a 6-foot-thick bed of dark-gray to black calcareous shale grading to shaly limestone (38–56 percent carbonate by chemical analysis) occurs 7 feet above the base. Moreover, the silt content of carbonate beds in the lower 10 feet of the Lodgepole is commonly high, and these beds may weather yellowish orange, as at Baker Mountain and at Picket Pin Ridge 12 miles southeast (fig. 1).

At sections between the eastern and western extremes of facies of the Cottonwood Canyon Member many other examples of gradation, interbedding, and continuity of lithologic features across contacts or facies boundaries exist. Only a few of these examples need be mentioned here for documentation. Carbonaceous shale of the Cottonwood Canyon Member is not only highly quartzose, as shown by its local gradations to carbonaceous dolomitic siltstone, but it is also highly dolomitic, as shown by its local gradations to carbonaceous shaly or silty dolomite. The carbonate content of this shale averages 20–40 percent in analyzed samples from widespread localities. At one locality, Picket Pin Ridge, the shale contains 50 percent carbonate. This high content closely resembles the content of shale interbeds—such as the one previously mentioned at Bandbox Mountain—in the undifferentiated part of the Lodgepole Limestone. It differs markedly, however, from the carbonate content of carbonaceous shale in the Devonian and Mississippian Bakken Formation, a partial equivalent of the Cottonwood Canyon in the Williston basin. Shale in the Bakken generally contains less than 10 percent carbonate. Carbonaceous siltstone of the shale and siltstone facies is also in part highly dolomitic and locally may grade to or contain interbeds of very silty dolomite. Conversely, silty dolomite of the dolomitic facies may locally grade to or contain interbeds of very dolomitic siltstone as well as wisps, laminae, and irregular patches that grade to dark-gray carbonaceous shale. *Zoophycus* markings, glauconite, and scattered crinoid columnals occur in silty dolomite and dolomitic siltstone of both facies. Perhaps the most conclusive proof of the close relation between the two facies of the Cottonwood Canyon Member and the undifferentiated lower beds of the Madison and Lodgepole Limestones is the occurrence of lithologically and faunally identical lag deposits at the base of the member, regardless of its facies, and at the base of the Lodgepole or Madison, where the member is too thin to be differentiated.

TONGUES

The Cottonwood Canyon Member comprises two tongues—a lower tongue and an upper tongue—whose conodont faunas and stratigraphic relations are recognizably different, as shown diagrammatically in figure 3. The lower tongue, which contains very late to possibly latest Devonian conodont faunas, is less extensive than the upper tongue and is present at the base of the Madison Limestone only in Wyoming. The upper tongue, which contains Early Mississippian conodont faunas, is widely distributed at the base of the Lodgepole Limestone in Montana and at or near the base of the Madison Limestone in Wyoming. The limit of the upper tongue generally coincides with the limit of the member (fig. 1). Both tongues occur together and in stratigraphic succession at some localities in northern Wyoming, where they are separated by a disconformity indicated both by cut-and-fill and by the absence from adjacent beds of conodont faunas that are represented elsewhere. At some localities in west-central Wyoming (fig. 3), however, the tongues are separated by undifferentiated beds of the Madison Limestone. At other nearby localities, where the lower tongue is poorly developed or not preserved, the member is represented only by its upper tongue, which lies 16–20 feet above a marked unconformity at the base of the Madison.

The lower tongue of the Cottonwood Canyon Member has been recognized at Shoshone and Cottonwood Canyons (fig. 4, cols. 5, 6), where it directly underlies the upper tongue, at Dinwoody Canyon (fig. 1), where it directly underlies beds of Devonian age in the undifferentiated part of the Madison Limestone, and at Bull Lake Canyon (fig. 1), where the directly overlying upper tongue is very thin. The lower 16 feet of the Madison Limestone at North Crazy Woman Canyon (fig. 1) is tentatively considered to represent the lower tongue of the member. The lower tongue may be present, although poorly developed, at the base of the Madison at Windy Gap. The lower tongue probably is also present at Clarks Fork Canyon (fig. 4, col. 4) and other measured sections that lie within the area of maximum accumulation. The precise contact between the two tongues in this area has not been clearly defined, however, because deposition of the member was more nearly continuous.

At Cottonwood Canyon (fig. 4, col. 6), the lower tongue is 10 feet thick and comprises units 2–4 of the type section. Each of these units, including the basal lag deposit (unit 2), yields an identical very late Devonian (upper *to*V) conodont fauna. The highest collection of this fauna comes from 1 foot below a wavy cut-and-fill surface, interpreted as a disconformity, at the top of unit 4. The upper tongue is represented by the next higher unit (5), which is 3 feet thick. Although unit 5 does not appear to have a basal lag deposit at the locality where the type section was measured, it is more silty than unit 4 and contains crinoid columnals, which do not occur in unit 4. These differences from unit 4 suggest changed depositional conditions. Furthermore, a Lower Carboniferous (upper *cu*I) conodont fauna is present throughout unit 5. At least one conodont zone that has been recognized in the member in the report area (fig. 3) and as many as three conodont zones that are reported elsewhere (Collinson and others, 1962, chart 6) are apparently missing between conodont collections from either side of the disconformity between units 4 and 5 and only 1 foot apart stratigraphically.

At Shoshone Canyon (fig. 4, col. 5), the lower tongue is 15 feet thick and the upper tongue is 8 feet thick. Each tongue yields a different conodont fauna and has a basal lag deposit. The lag deposit of the lower tongue contains a very late Devonian (upper *to*V) conodont fauna, whereas the lag deposit and upper part of the upper tongue both contain a Lower Carboniferous (upper *cu*I) conodont fauna.

At Dinwoody Canyon on the east side of the Wind River Range (fig. 1), the lower tongue is 6 feet thick and contains a very late Devonian (upper *to*V) conodont fauna. It is overlain by undifferentiated Madison Limestone that in its lower 16 feet also contains a very late Devonian (upper *to*V) conodont fauna, as determined from five conodont collections at stratigraphic intervals of 2–4 feet. Directly above these Devonian beds, pronounced related changes in lithologic character and bedding thickness suggest a disconformity or hiatus at a horizon where the upper tongue would be expected to occur on the basis of correlation with the nearby Windy Gap section (fig. 1). The physical break at this horizon apparently coincides with a faunal change. Lower Carboniferous (*cu*I–IIα) conodonts were collected from a bed 5 feet higher in the Madison.

At Bull Lake Canyon (fig. 1), the southernmost outcrop at which it has been differentiated from the Madison Limestone in the Wind River Range, the Cottonwood Canyon Member is greatly condensed. Although only 1.2 feet thick, the member apparently comprises both tongues in a section measured on the north wall of the canyon. The lower tongue is 0.8 foot thick and the upper tongue is 0.4 foot thick. Each tongue has a very thin basal sandy shale and a different conodont fauna. The lower tongue contains a very late Devonian (upper *to*V) fauna. The upper tongue, which is bed 2 of Klapper (1958) on the south side of the canyon, contains an Early Mississippian (Kinderhook) conodont fauna identified by J. W. Huddle (written commun., 1964). Although this fauna is not large nor well preserved, it includes fragments of siphonodellids, which indicate an age younger than earliest Mississippian (fig. 3).

At North Crazy Woman Canyon, a 16-foot-thick unit consisting predominantly of light-colored hematitic slightly silty dolomite but containing interbeds of very sandy dolomite and silty shale in its basal 3 feet is tentatively assigned to the lower tongue. This unit underlies the upper tongue of the Cottonwood Canyon Member, which is 6 feet thick at this locality. The clastic content of the upper part of the 16-foot unit is so low, however, that only the basal 3 feet alternatively might be considered the lower tongue. By this interpretation, the upper 13 feet would be considered a tongue of undifferentiated Madison Limestone intervening between tongues of the Cottonwood Canyon Member. The alternative interpretation is regarded as less likely, however, because of the uncommonly high hematite content of the upper 13 feet. Regardless of whether all or part of the 16-foot unit represents the lower tongue, the assignment of the entire unit to the Madison is unequivocal. The unit contains a conodont fauna that lacks species diagnostic for a zonal assignment but includes a new genus, provisionally designated as ?*Scaphignathus velifera* by Glenister and Klapper (1966, pl. 94, fig. 3), that occurs in the uppermost Devonian (*to*V–VI) of Western Australia. Previously the unit was included incorrectly in the Jefferson Formation of early Late Devonian age (Sandberg, 1961, pl. 6).

At all other localities where the presence or probable presence of the lower tongue is not mentioned here, the member comprises only the upper tongue, which generally but not everywhere lies at the base of the Madison or Lodgepole Limestone. Several localities where the member consists only of the upper tongue and yields a diagnostic conodont fauna are shown in figure 4 (cols. 1–3, 7). Also, only the upper tongue is present at the reference well. Other well-exposed sections, where the member is constituted by its upper tongue and where diagnostic conodont faunas may be collected, are readily accessible on roads through the Bighorn Mountains. These sections include: Little Tongue Canyon, along U.S. Highway 14, 19 miles west of Sheridan; Tensleep Canyon, north of U.S. Highway 16 and 25 miles southeast of North

Crazy Woman Canyon; and Shell Canyon, north of U.S. Highway 14 (fig. 1).

One of the most significant measured sections of the Cottonwood Canyon Member and of the undifferentiated lower part of the Madison Limestone is at Windy Gap in the Washakie Range, Wyo. (fig. 1). There, the lower tongue is poorly developed and is tentatively considered to be represented by a ½-foot-thick bed of silty dolomite without a lag deposit at the base of the Madison. This bed contains a very late Devonian (upper *to*V) conodont fauna. The next two higher beds of dolomite in the Madison, which aggregate 15½ feet in thickness and contain *Syringopora* sp. and other corals, are probably of about the same age. Their lithologic character and thickness closely match those of the Devonian part of the Madison at Dinwoody Canyon, 21 miles to the south in the Wind River Range. The well-developed upper tongue of the Cottonwood Canyon Member, which lies 16 feet above the base of the Madison, is about 3 feet thick and yields two different conodont faunas. An earliest Mississippian conodont fauna, assigned to the *Siphonodella sulcata* (lower *cu*I) Zone, is present in three thin beds of pinkish-gray silty dolomite within the basal 1 foot of the upper tongue. This is the only fauna of this age that was found in the present study. The second conodont fauna, which indicates an Early Mississippian (upper *cu*I) age, is from a 1-foot-thick bed in the middle of the tongue. A fauna of this same age also was found in undifferentiated beds of the Madison, 1 foot above the top of the upper tongue. The stratigraphic and age relations of the upper tongue at Windy Gap provide further proof of intertonguing between the Cottonwood Canyon Member and the undifferentiated lower part of the Madison Limestone.

AGE

The age of the Cottonwood Canyon Member, based on conodont determinations, ranges from very late Devonian to Early Mississippian in Wyoming, but it is entirely Early Mississippian in Montana. The presence of the lower tongue in Wyoming accounts for the slightly older age of the member there. In terms of ammonoid Stufen, the member ranges from the upper part of the *Clymenia*-Stufe of the Upper Devonian to the lower part of the *Pericyclus*-Stufe of the Lower Carboniferous (fig. 3). To state the age using the symbols that are conventionally employed to express ages based on conodont determinations, the Cottonwood Canyon ranges in age from upper *to*V to lower *cu*IIα.

The lower tongue of the Cottonwood Canyon Member generally yields a very late Devonian (upper *to*V) conodont fauna. At North Crazy Woman Canyon and other nearby localities in the central Bighorn Mountains (fig. 1), however, it yields an impoverished conodont fauna dominated by *?Scaphignathus velifera* that may suggest an age as young as latest Devonian (*to*VI). The more widespread upper tongue yields three successive Early Mississippian conodont faunas—lower *cu*I, upper *cu*I, and lower *cu*IIα. The upper *cu*I and lower *cu*IIα faunas are widespread, but the lower *cu*I fauna was found only at Windy Gap, Wyo. The scarcity of the latest Devonian (*to*VI) and earliest Mississippian (lower *cu*I) faunas in the member and in the undifferentiated lower part of the Madison Limestone might be attributed to inadequate sampling or to unsuccessful differentiation of slightly older and younger faunas. These explanations seem unlikely, however, because of the large number of samples that were processed from stratigraphic intervals of only a few inches at several localities and because of the many phylogenetic sequences of conodonts that were recognized. A more likely explanation of the scarcity of *to*VI and lower *cu*I faunas is provided by regional paleotectonic events, which will be interpreted later.

CORRELATION

The Cottonwood Canyon Member of the Madison Limestone is equivalent to the Devonian and Mississippian Englewood Formation, which crops out below the Pahasapa Limestone, a partial equivalent of the Madison, in the Black Hills of northeastern Wyoming and western South Dakota. The lithologic character, stratigraphic relations, thickness, and age of the Englewood and Cottonwood Canyon are very similar, as discussed by Sandberg (1963). The equivalence of their conodont faunas was discussed by Klapper (1966).

The Englewood Formation occupies a narrow elongate area 70–270 miles wide and 450 miles long that trends about N. 42° E. from the southeastern Powder River Basin, Wyo., through the Black Hills to the eastern Williston basin in northeastern North Dakota. Its thickness ranges from 18 to 54 feet at outcrops in the Black Hills and reaches a maximum of about 90 feet at a depositional center in the subsurface of north-central South Dakota.

The Englewood Formation and Cottonwood Canyon Member are now separate rock bodies although their limits locally are only about 30 miles apart in the subsurface of the Powder River Basin. Their original depositional areas may have coalesced briefly in Early Mississippian time, but vestiges of any very thin connecting shelf deposits are difficult to locate because of sparse subsurface control. A hypothesized connection between the two rock bodies may be documented by further study of outcrops in the Hartville Uplift, southeast of the Powder River Basin in east-central Wyoming. There, at Ragan Draw, a conodont-bearing sandstone that is lithologically similar to both units has been found at the base of the Guernsey Formation of Devonian and Mississippian age.

The Cottonwood Canyon Member was deposited penecontemporaneously with a complex of related thin carbonaceous Devonian and Mississippian strata that extends arcuately from the Williston basin in North Dakota through southern Manitoba, southern Saskatchewan, and northern Montana northwestward into Alberta and then southward into southwestern Montana. This complex comprises three partly connected units that had discrete depositional centers: the Bakken Formation in the Williston basin, the Exshaw Formation in Alberta, and the Sappington Member of the Three Forks Formation in southwestern Montana. The Bakken Formation comprises upper and lower transgressive black shales separated by a medial siltstone. Because of later erosion, the upper black shale of the Bakken now extends only as far west as north-central Montana, but the medial siltstone and lower black shale continue into Alberta, where they form the Exshaw Formation. The black shale of the Exshaw, which commonly has a very thin lag sandstone at its base, extends southward into Montana and connects with the basal black shale of the Sappington in southwestern Montana. The upper siltstone of the Exshaw is separated from the equivalent units (2–5) of the Sappington, however, by a 40-mile-wide area of erosional thinning in northwestern Montana. Thus, despite later erosion, the lower black shale remains continuous between all three units of this depositional complex, and the overlying siltstone is only narrowly separated.

The age equivalence of the complex of Devonian and Mississippian strata on the north to the Cottonwood Canyon Member has not been firmly established on the basis of conodonts, but it can be indirectly approximated from known stratigraphic relations and from widely scattered conodont evidence.

The lower black shale of the complex, at least where it forms the base of the outcropping Sappington Member of the Three Forks Formation, is dated from conodonts as very late Devonian (lower *to*V), which is older than the lower tongue of the Cottonwood Canyon Member (fig. 3). As this lower shale is transgressive and the direction of transgression is unknown, its age beneath the Sappington does not precisely establish its age beneath the Exshaw or Bakken Formation, where it may be either slightly older or slightly younger. The Bakken and Exshaw occur largely in the subsurface in North Dakota and northern Montana, where their conodont faunas are not well known. In eastern Alberta, however, conodont evidence suggests that the lower black shale is approximately the same age—very late Devonian—at the base of the Bakken as it is at the base of the Sappington. A supposed Kinderhook conodont fauna was described by Cooper (Cooper and Sloss, 1943) from a subsurface unit informally called "Exshaw" in the Steveville oil field of eastern Alberta. This subsurface unit is now regarded as the lower black shale of the Bakken, according to Penner (1958). The conodont fauna figured by Cooper and Sloss (1943) was reevaluated in the light of more recent evidence of conodont zonation (Klapper, 1966, p. 10); it contained no species diagnostic of a Kinderhook age but did contain two species indicative of very late Devonian (*to*V–VI) age.

The age of the top of the complex can also be indirectly dated by correlating from outcrops to the subsurface. The top of the Sappington, although not precisely dated, must be the same age as or slightly older than the overlying Cottonwood Canyon where they occur together in stratigraphic succession. The age of the top of the Sappington, however, does not definitely establish the upper age limit of the Exshaw Formation nor of the Bakken Formation. These formations are thicker and contain beds stratigraphically higher than the upper part of the Sappington. Consequently, their upper age limit may be roughly the same as youngest part of the Cottonwood Canyon, which is Early Mississippian (Kinderhook), equivalent to the Lower Carboniferous (lower *cu* IIα) of Europe. An age no younger than lower *cu*IIα for the Bakken is supported by collections of conodonts diagnostic of that age from basal beds of the Lodgepole Limestone, which directly overlies the upper shale of the Bakken in the Little Rocky Mountains of north-central Montana. Although this is the only area in which the Bakken is known to crop out on the margins of the Williston basin, the outcrops lie close to the limit of the farthest southward transgression by the upper shale of the Bakken in north-central Montana. Hence, the Bakken probably is as young there as anywhere in the subsurface.

In summary, although the northern complex has not been conclusively dated on the basis of conodonts, its age can be inferred to range approximately from very late Devonian (lower *to*V) to Early Mississippian (lower *cu*IIα).

MADISON LIMESTONE (LOWER PART)

GENERAL FEATURES

The lower 10–25 feet of the undifferentiated part of the Madison Limestone in all of Wyoming except the extreme western part, where the Lodgepole Limestone is recognized, consists largely of light-colored microcrystalline to very finely crystalline microsucrosic to sucrosic slightly crinoidal dolomite. The most commonly observed colors of freshly broken rock surfaces are yellowish gray, light olive gray, and light gray. Less common colors, in decreasing order of abundance, are pale yellowish brown, medium light gray, grayish orange pink, very light gray, yellowish orange, medium gray, light brownish gray, yellowish orange, grayish orange, and pale yellow. The dolomite commonly is slightly calcitic and less commonly is calcitic, but the calcite content approaches that of dolomitic limestone. The dolomite may be characterized as slightly silty to nonsilty; analyses of more than 25 samples from about 15 widespread localities show that the silt content ranges from 3 to 17 percent and averages about 10 percent. Glauconite grains are rare, but scattered very fine to coarse quartz sand grains locally are present in the basal few inches. Crinoid columnals are not as large nor as abundant as those in the Lodgepole Limestone farther north and west, but they do occur at most sections. Even in samples in which crinoid columnals or their molds are not discernible megascopically or microscopically, differentially dolomitized columnals can be etched from the dolomite by partial solution in acetic acid.

The thickness of the beds in the lower 10–25 feet of the Madison is generally 4 feet or greater, but it may be as little as 1–2 feet, particularly in the basal 10 feet. Although the lower part of the Madison generally forms part of a high cliff or thick resistant ledges, the basal 10 feet characteristically forms a reentrant in the cliff face or thinner less resistant ledges than those above.

Two diagnostic features of the basal beds of the undifferentiated lower part of the Madison in outcrop are the high vuggy porosity and the common occurrence of *Syringopora* sp. corals, which are not present in underlying Devonian formations. The vuggy porosity results from the presence of abundant leached fossil molds, which were formed during dolomitization of the original limestone. Many of the fossil molds are of crinoid columnals. Large colonies of *Syringopora* sp. occur in the basal 10 feet, generally where the silt content is low and particularly in the Bighorn and Owl Creek Mountains and Wind River Range.

Large well-preserved conodont faunas generally are more difficult to obtain from the basal part of the undifferentiated Madison Limestone in Wyoming than from the corresponding part of the Lodgepole Limestone in Montana and western Wyoming. The scarcity of conodonts in the Madison is believed to be due to a facies change that affected their rate of accumulation and to the widespread dolomitization in central and eastern Wyoming. The crinoid content was noted to be much lower in rocks of the Madison in the area east of the belt of maximum thickness of the Cottonwood Canyon Member than in rocks of the Lodgepole in the area on the west. A correspondingly abrupt eastward change in the content of glauconite and chert was also noted. The environment of deposition of the basal Madison is therefore believed to differ from that of the basal Lodgepole, and it probably was less favorable for the concentration of conodonts. Furthermore, many of the larger conodonts obtained from dolomite of the Madison are badly broken. This may result partly from their breakage prior to deposition and partly from their fragmentation during dolomitization.

In the Pryor and northern Bighorn Mountains of south-central Montana (fig. 2), the basal 25 feet of the undifferentiated lower part of the Madison Group is dolomite that is lithologically identical with the dolomite at the base of the Madison in most of Wyoming. This area of Montana also lies east of the belt of maximum accumulation of the Cottonwood Canyon Member. Beds directly above the basal 25 feet in the Pryor Mountains are very cherty dolomite and dolomitic limestone. Their chert content is similar to that of the basal Lodgepole Limestone farther west in Montana.

AGE

The age of the basal part of the Madison Limestone in Wyoming ranges from very late Devonian (upper *to*V) to Early Mississippian (Kinderhook), equivalent to the *Gattendorfia-* or *Pericyclus*-Stufe (*cu*I–IIα) of the Lower Carboniferous of Europe. Collections of conodonts suitable for approximate age determinations were found in the undifferentiated lower part at many localities, but only several collections were sufficiently large and well preserved to be assigned to one of the established conodont zones. Five collections of conodonts diagnostic of a very late Devonian (upper *to*V) age were made at Dinwoody Canyon, and collections diagnostic of the Lower Carboniferous (upper *cu*I) were made directly above the Cottonwood Canyon Member at Clarks Fork Canyon (fig. 4, col. 4) and at Windy Gap. Collections indicative of an Early Mississippian (Kinderhook) age but containing species that range from upper *cu*I to lower *cu*IIα were made at Bull Lake, Little Tongue, and Cottonwood Canyons. At most other localities, age assignments of the undifferentiated part of the Madison were based on the presence of broken siphonodellids, indicative of a Mississippian (Kinderhook) age, and were supported by well-dated conodont faunas from the underlying or interbedded Cottonwood Canyon Member.

LODGEPOLE LIMESTONE (LOWER PART)

GENERAL FEATURES

The basal 10 feet of the undifferentiated lower part of the Lodgepole Limestone at Peak 9559 in the Bridger Range, at the type section of the Madison Group near Logan, Mont., and in most other areas farther west and north in Montana has a nearly uniform lithologic character. It consists of medium-gray to medium-dark-gray bioclastic limestone that is microcrystalline to cryptocrystalline and medium to very coarsely fossil fragmental and contains abundant glauconite. It is composed largely to almost entirely of crinoid columnals and fragments. The columnals range from 1/8 to 1/2 inch in diameter. In and near the Little Belt Mountains, this limestone may contain lenses or very thin to thick interbeds of black calcareous shale grading to very shaly limestone. At the mouth of Swimming Woman Canyon, on the south side of the Big Snowy Mountains (located but not named in fig. 1), well-exposed porous bioherms composed almost entirely of dolomitized algae and crinoid fragments interrupt the normal stratigraphic sequence and extend upward through surrounding thin beds for at least 150 feet above the base of the Lodgepole. A bioherm was also observed at Bandbox Mountain in the Little Belt Mountains, but its base was about 125 feet above the base of the Lodgepole.

South and east of the Bridger Range, the basal 10–25 feet of the Lodgepole Limestone in the Gallatin Range and Beartooth Mountains, Mont., and the Teton Range, Wyo., differs slightly in lithologic character from areas farther north and west. It generally consists of medium-gray, medium-light-gray, light-olive-gray, and yellowish-gray slightly argillaceous crinoidal limestone that is microcrystalline to finely crystalline, medium to coarsely fossil fragmental, and commonly dolomitic to slightly dolomitic. This limestone is slightly less glauconitic and crinoidal than that in areas farther north and west, but crinoidal debris commonly constitutes 25–50 percent and rarely as much as 75 percent of the rock. Chert is generally present and locally very abundant. Large chert nodules or stringers as much as 3 inches thick and 10 feet long may constitute as much as 20 percent of the rock. This very cherty zone is at the base of the undifferentiated part of the Lodgepole in some areas, but elsewhere the basal 2–12 feet may be relatively chert free. The zone appears to rise stratigraphically toward the southeast.

A lower crinoidal unit of the Lodgepole Limestone in western Wyoming and southwestern Montana was also recognized by Sando and Dutro (1960), who reported that it contained a Zone A megafauna.

The thickness of bedding in the lower 10–25 feet of the undifferentiated part of the Lodgepole Limestone ranges from 4 inches to 4 feet but is most commonly about 2 feet. This basal part of the Lodgepole is commonly more resistant than the overlying part and forms a low cliff or moderately resistant ledge.

The most diagnostic features of the basal carbonate beds of the Lodgepole in outcrop are their moderate to high glauconite content, high to very high crinoid content, and moderate to high content of white, bluish-white, light-olive-gray, olive-gray, or medium-dark-gray spicular chert. These features also serve to identify the basal 10–15 feet of the Lodgepole in the subsurface throughout eastern Montana and North Dakota. The high glauconite content is observable in both well cuttings and cores. Moreover, the uniformly high total carbonate content of the crinoidal limestone is represented on radioactivity well logs by a deflection of the gamma-ray curve to the left. This deflection is most striking on logs from wells where overlying beds of the Lodgepole are largely thin-bedded argillaceous limestone grading to calcareous shale.

Conodonts are characteristically abundant and well preserved in the lower 10 feet of the undifferentiated part of the Lodgepole Limestone and particularly in the basal few inches of the more calcareous facies in the northern and western areas of Montana. Conodonts in these beds, unlike those at some places in the Cottonwood Canyon Member, are generally not recognizable on either fresh or weathered surfaces.

AGE

The basal part of the undifferentiated lower part (or locally of the Paine Shale Member) of the Lodgepole Limestone is Early Mississippian (Kinderhook), equivalent to a part of the *Pericyclus*-Stufe (lower *cu*II*α*) of the Lower Carboniferous of Europe. It is also a time equivalent of the upper part of the Hannibal Shale and lower part of the Chouteau Limestone of the Upper Mississippi Valley (Collinson and others, 1962). Conodont faunas indicative of this age are present at every sampled section of the Lodgepole in north-central, central, west-central, southwestern, and south-central Montana. The localities include: (1) Little Chief Canyon in the Little Rocky Mountains, where the Lodgepole Limestone was named, north of the report area, (2) Bandbox Mountain, (3) Crystal Lake Road on the north side of the Big Snowy Mountains (located but not named in fig. 1), (4) Peak 9559, (5) Mystic Lake in the north-central Gallatin Range (located but not named in fig. 1), (6) Castle Rock in the west-central Beartooth Mountains (located but not named in fig. 1), (7) Baker Mountain, and (8) Meridian Ridge. The basal carbonate beds of the Lodgepole also contain a lower *cu*II*α* conodont fauna at the type section of the Madison Group at Logan and at six other nearby localities which lie within an 11-mile radius of Three Forks, Mont. These localities, which are located but not named in figure 1, are Nixon Gulch, Rekap Station, Mud Spring Gulch, Milligan Canyon, Dry Hollow, and Ingleside Quarry. Lower *cu*II*α* conodonts are also present in the basal carbonate beds of the Lodgepole at Teton Canyon, Wyo. (fig. 1).

CONODONT ZONES

The conodont zonation of the Three Forks Formation, the Cottonwood Canyon Member (dark shale unit), and the basal strata of the Madison and Lodgepole Limestones was previously discussed by Klapper (1966, p. 11–12 and fig. 2). Additional comments on this zonation are made here to incorporate findings based on more recent conodont collections that are listed elsewhere in this report. A conodont zone that previously was treated informally by Klapper (1966) is here named the *Siphonodella sandbergi–Siphonodella duplicata* Zone. The first finding of the *Siphonodella sulcata* Zone of Collinson, Scott, and Rexroad (1962) in the Northern Rocky Mountains region is recorded from Windy Gap in west-central Wyoming (fig. 1). The conodont zones that are presently recognized in the Upper Devonian and Lower Mississippian of Wyoming and Montana are shown in figure 3.

UPPER DEVONIAN ZONES

SCAPHIGNATHUS VELIFERA ZONE (UPPER *to*III*α*–LOWER *to*IV)

A conodont fauna found in the top 2 feet of the Trident Member of the Three Forks Formation at Peak 9559 is assigned to the *Scaphignathus velifera* Zone (Ziegler, 1962). The *S. velifera* represented in this fauna resembles the form with a low free blade that was illustrated by Ziegler (1962, pl. 11, fig. 19) from the Upper *S. velifera* Zone (upper *to*III*β*–lower *to*IV) at Ball-Berg, Rhenish Schiefergebirge, Germany. *Polygnathus communis* has a questionably lowest occurrence in the Upper *S. velifera* Zone but is definitely found as low as the directly overlying Lower *P. styriaca* Zone according to Ziegler (1962, p. 88). *P. perplexa* occurs in higher *to*III and in *to*IV strata (Helms, 1961, p. 693). *P. irregularis* (Thomas) [not Cooper] is found in highest *to*IV strata (Helms, 1961, p. 686). Thus the fauna at Peak 9559 suggests a correlation with the Upper *S. velifera* Zone, although the occurrence of *Pseudopolygnathus granulosa* Ziegler would be necessary to establish this more precise correlation.

A fauna that is similar to the one at Peak 9559 in that it also contains both *Scaphignathus velifera* and *Polygnathus semicostata* was reported from the Upper Famennian (*Fm*2a) of Belgium in beds 62 and 63 of the Grès de Montfort section by Bouckaert and Ziegler (1965, p. 16 and chart 8).

UPPER POLYGNATHUS STYRIACA ZONE (LOWER toV)

The fauna from the basal lag deposit (sample BB–15) of the Sappington Member of the Three Forks Formation at Bandbox Mountain is assigned to the Upper *Polygnathus styriaca* Zone. It includes three significant taxa: *Palmatolepis rugosa postera*, *Spathognathodus jugosus*, and *Pseudopolygnathus marburgensis*. The highest occurrence of *P. rugosa postera* and the lowest occurrence of *S. jugosus* are diagnostic of this zone, according to Ziegler (1962, table 2). The overlap in ranges of these two taxa occurs in four samples from the Upper *P. styriaca* Zone at the Hönnetal roadcut, near the Hönnetal railroad cut, in the Rhenish Schiefergebirge (Ziegler, 1962, table 5). In addition, *P. marburgensis* is restricted to the same zone at Ziegler's Hönnetal locality.

The finding of a large well-preserved fauna at Bandbox Mountain confirms the previously reported finding of the Upper *Polygnathus styriaca* Zone in the basal part of the Sappington Member at Frazier Lake, just north of Peak 9559 in the Bridger Range (Klapper, 1966, p. 7). Unlike the Bandbox Mountain fauna, the Frazier Lake fauna was obtained from a hydrofluoric acid residue, and the conodonts were not well preserved because of chemical change caused by the acid.

LOWER SPATHOGNATHODUS COSTATUS ZONE (UPPER toV)

Faunas referable to this zone were described from the lower tongue of the Cottonwood Canyon Member at Cottonwood, Dinwoody, and Bull Lake Canyons, from the basal 4 feet of the Madison Limestone at Dinwoody Canyon, and from the middle part of the Englewood Formation in the Black Hills by Klapper (1966). Listed elsewhere in this report are the more relevant of these faunas, as well as previously unlisted faunas from the Lower *Spathognathodus costatus* Zone. The previously unlisted faunas are from the lower tongue of the Cottonwood Canyon Member at Shoshone Canyon, and from 12–16 feet above the base of the Madison Limestone at Dinwoody Canyon. This zone is also present but represented only by a sparse fauna in the undifferentiated part of the Madison Limestone between the two tongues of the Cottonwood Canyon Member at Windy Gap.

A fauna from the 16-foot-thick unit tentatively assigned to the lower tongue of the Cottonwood Canyon Member at North Crazy Woman Canyon is dominated by a new genus, which was provisionally designated as ?*Scaphignathus velifera* by Glenister and Klapper (1966, p. 834, and pl. 94, fig. 3). The new genus is present in the uppermost Devonian (*to*V–VI) beds of the Fairfield Formation in Western Australia (Glenister and Klapper, p. 838, sample GSWA 3240). It does not occur with other diagnostic taxa in the Wyoming fauna, however. In the absence of other evidence, it is suggested that the beds containing ?*Scaphignathus velifera* at North Crazy Woman Canyon may be uppermost Devonian and thus somewhat younger than the Lower *Spathognathodus costatus* Zone.

LOWER MISSISSIPPIAN ZONES

The *Gattendorfia*-Stufe (*cu*I) of the Lower Carboniferous in Germany was divided into three conodont zones by Voges (1959, 1960). These zones in ascending order are the *Gnathodus kockeli–Pseudopolygnathus dentilineata* Zone, the *Siphonodella–Pseudopolygnathus triangula inaequalis* Zone, and the *Siphonodella–Pseudopolygnathus triangula triangula* Zone. Voges based this zonation on samples of the Hangenberg Limestone mainly at the Hönnetal railroad cut, Sauerland, Rhenish Schiefergebirge, but also at three other sections of the Hangenberg in the Sauerland. The Hönnetal railroad cut is the formal reference section for the Devonian-Carboniferous boundary, as decided by the Second Carboniferous Congress at Heerlen, Netherlands, in 1935. (See Voges, 1960, figs. 1, 2, for locations of these sections.)

The concept of *Siphonodella duplicata* as used by Voges (1959) is much broader than that later employed by Collinson, Scott, and Rexroad (1962) and by Klapper (1966). Because Voges included both *S. duplicata* s.s. and *S. cooperi* in *S. duplicata*, the correlation of his zones with North American *cu*I faunas, in which *S. duplicata* s.s. is differentiated, is difficult. Sampling of *cu*I strata at the Hönnetal railroad cut by Klapper in 1963, however, clarifies some aspects of this problem, as summarized below.

The *Gnathodus kockeli–Pseudopolygnathus dentilineata* Zone, the lowest of Voges' three conodont zones, includes his Hönnetal samples 1–4 (Voges, 1959, p. 270 and fig. 1). Our sample X–41, which represents the combined interval of Voges' samples 3 and 4, contains *Siphonodella sulcata*. This finding extends the range of *Siphonodella* downward into the *G. kockeli–P. dentilineata* Zone.

The overlying *Siphonodella–Pseudopolygnathus triangula inaequalis* Zone includes Hönnetal samples 5–9 of Voges (1959, p. 270 and fig. 1). Our samples X–42 and X–43 are equivalent to Voges' samples 5 and 6, respectively, and mark the lowest occurrence of *S. duplicata* s.s. *S. sandbergi* occurs in our sample X–45, which is equivalent to Voges' Hönnetal sample 9.

In Wyoming only two *cu*I conodont zones—the *Siphonodella sulcata* Zone and the *Siphonodella sandbergi–Siphonodella duplicata* Zone—are recognized. An exact correlation between these two zones and Voges' three conodont zones in Germany cannot be made at present, but a tentative correlation is suggested. The *S. sulcata* Zone, which is here designated as lower *cu*I, probably is correlative with the higher part of the *Gnathodus kockeli–Pseudopolygnathus dentilineata* Zone of Voges. The *S. sandbergi–S. duplicata* Zone, which is here arbitrarily designated as upper *cu*I, seems to be correlative with both the *Siphonodella–P. triangula inaequalis* and the *Siphonodella–P. triangula triangula* Zones of Voges. Consequently, the designations lower *cu*I and upper *cu*I, as used herein, do not refer to formal subdivisions of *cu*I but merely indicate relative positions within *cu*I.

SIPHONODELLA SULCATA ZONE (LOWER cuI)

The faunas in three samples (WG–20, WG–1, and WG–22) from the basal 1 foot of the upper tongue of the Cottonwood Canyon Member at Windy Gap, Wyo., apparently correlate with the *Siphonodella sulcata* Zone of Collinson, Scott, and Rexroad (1962, p. 20). The finding of *S. sulcata* in strata equivalent to Voges' samples 3 and 4 at the Hönnetal railroad cut suggests that the Windy Gap faunas, although they lack *Gnathodus kockeli*, also correlate with the *G. kockeli–Pseudopolygnathus dentilineata* Zone of Voges (1960).

SIPHONODELLA SANDBERGI–SIPHONODELLA DUPLICATA ZONE (UPPER cuI)

The "Montana and Wyoming *cu*I" zone of Klapper (1966, p. 11–12 and fig. 2) is here formally named the *Siphonodella sandbergi–Siphonodella duplicata* Zone to avoid confusion with the older *cu*I *Siphonodella sulcata* Zone now recognized at Windy Gap. Faunas referable to the *S. sandbergi–S. duplicata* Zone were reported from six localities by Klapper (1966, table 1). Five of these occurrences are in the upper tongue of the Cottonwood Canyon Member; the sixth is in the basal 1 inch of the undifferentiated Madison Limestone at Clarks Fork Canyon. Previously unreported occurrences of the zone are in the upper tongue of the Cottonwood Canyon Member at Clarks Fork, Shoshone, Warm Spring, Shell, and North Crazy Woman Canyons and at Horse Creek and Windy Gap. The zone also occurs in the undifferentiated lower part of the Madison Limestone directly above the upper tongue of the Cottonwood Canyon at Windy Gap.

In faunas at two localities in Wyoming—Warm Spring Canyon and Horse Creek—the siphonodellids are predominantly *Siphonodella duplicata*. The fauna from sample HC–7F at Horse Creek resembles faunas obtained from strata equivalent to Hönnetal samples 5 and 6 of Voges (1959, p. 270 and fig. 1), in which the dominant siphonodellid is also *S. duplicata*. This suggests a correlation of the HC–7F fauna with a position low in Voges' *Siphonodella–Pseudopolygnathus triangula inaequalis* Zone, although the zonal name-bearing *Pseudopolygnathus* has not yet been found in the Wyoming faunas.

In faunas at most of the other upper *cu*I localities in Montana and Wyoming, *Siphonodella duplicata* and *S. sandbergi* occur together with *S. cooperi*, *S. quadruplicata*, *S. obsoleta*, and rare *S. sexplicata*. These faunas appear to correlate with a position high in the *Siphonodella–P. triangula inaequalis* Zone (Voges, 1959, Hönnetal sample 9) or low in the *Siphonodella–P. triangula triangula* Zone for reasons Klapper stated previously (1966, p. 12).

Future work may permit the *Siphonodella sandbergi–S. duplicata* Zone to be separated into an older part in which only *S. duplicata* and rare *S. sulcata* are present and a younger part in which both zonal name-bearers are present. Faunas that are representative of the two prospective parts of this zone are listed elsewhere in the report. Significantly, at one locality—Horse Creek, Wyo.—both the older and younger faunas are present in succession within the upper tongue of the Cottonwood Canyon Member.

LOWER SIPHONODELLA CRENULATA ZONE (LOWER cuIIα)

The fauna of the Lower *Siphonodella crenulata* Zone was described from basal beds of the undifferentiated part of the Lodgepole Limestone at 10 localities by Klapper (1966). Previously unreported occurrences of this zone are in the basal beds of the Lodgepole at Bandbox Mountain, Little Chief Canyon, Mystic Lake, Castle Rock, Mud Spring Gulch, and Meridian Ridge. The zone also is recognized in the upper tongue of the Cottonwood Canyon Member at Meridian Ridge. The fauna from this latter occurrence seems to extend the range of *Pseudopolygnathus dentilineata* upward from the top of *cu*I into the Lower *S. crenulata* Zone. The base of the Lower *S. crenulata* Zone is recognized primarily by the lowest occurrence of the zonal name-bearer but also by the lowest occurrence of *P. marginata* and the abundant occurrence of *P. triangula triangula*. Only one specimen of the latter taxon has been found below *cu*IIα in upper *cu*I strata at Baker Mountain (Klapper, 1966, table 1, loc. 9).

REPRESENTATIVE CONODONT COLLECTIONS

The conodont collections listed below present the diagnostic faunas that were found at all the localities shown in the cross section (fig. 4) and at the more significant localities mentioned in the stratigraphic discussion. Representative conodont collections are given for each geologic unit that bears a single conodont zone and for each conodont zone within geologic units that bear two or more zones. The number of specimens identified is shown in parentheses. Conodonts that are believed to be reworked from lower strata are indicated by an asterisk preceding the generic name.

TRIDENT MEMBER OF THREE FORKS FORMATION

The following fauna was obtained from a 2-foot-thick bed of limestone at the top of the Trident Member of the Three Forks Formation at Peak 9559, south of Hardscrabble Peak in the Bridger Range. The locality is at an elevation of about 9,280 feet in the SE¼ SE¼ SE¼ sec. 21, T. 2 N., R. 6 E., Gallatin County, Mont., in the Sedan 15-minute quadrangle. The fauna is assigned to the *Scaphignathus velifera* Zone, which indicates a Late Devonian (Upper Famennian, upper *to*IIIα–lower *to*IV) age.

Scaphignathus velifera Helms (3)
Polygnathus irregularis (Thomas) [not Cooper] (1)
P. perplexa Thomas (2)
P. semicostata Branson and Mehl (7)
P. communis Branson and Mehl (8)
Pelekysgnathus communis Thomas (2)
Apatognathus varians Branson and Mehl (early form) (3)

A nearly identical fauna containing abundant well-preserved specimens of *Scaphignathus velifera* is present in limestone at the top of the Trident Member at Sheep Mountain in the Centennial Range, Mont. This locality is just north of the Idaho State line at the west edge of the report area (fig. 1). It is at an elevation of about 7,800 feet near the center of the west edge of sec. 28, T. 14 S., R. 1 W., Beaverhead County, Mont., in the Upper Red Rock Lake 15-minute quadrangle.

A fauna that has several species in common with the fauna at Peak 9559 was found in a 2-inch-thick bed of limonitic bioclastic limestone, which is interbedded with greenish-gray shale, in the top 5 feet of the Trident Member 2 miles north of Mud Spring Gulch. This locality at an elevation of about 4,630 feet, is in the center NE¼SW¼ sec. 1, T. 2 N., R. 1 E., Broadwater County, Mont., in the Three Forks 15-minute quadrangle. The fauna, which is listed below, lacks the zonal name-bearer and therefore cannot be referred to the *Scaphignathus velifera* Zone with certainty.

Polygnathus irregularis (Thomas) [not Cooper] (1)
P. semicostata Branson and Mehl (31)
Pelekysgnathus communis Thomas (4)
Apatognathus varians Branson and Mehl (early form) (23)
Spathognathodus stabilis (Branson and Mehl) (5)

SAPPINGTON MEMBER OF THREE FORKS FORMATION

The conodont fauna listed below was obtained from sample BB–15 at a section of the Three Forks Formation and lower part of the

Lodgepole Limestone measured on the west face of Bandbox Mountain in the Little Belt Mountains. The locality is about 250 feet vertically below the 7,952-foot summit of the mountain in the NE¼NW¼ sec. 20, T. 14 N., R. 10 E., Judith Basin County, Mont., on the White Sulphur Springs 1:250,000 Army Map Service sheet NL 12–5. Sample BB–15 represents the basal limonitic conglomeratic lag sandstone, 0–2 inches thick, of the Sappington Member. Conodonts are abundant on the weathered surfaces of the rock and are readily visible under a × 10 hand lens. The fauna is assigned to the Upper *Polygnathus styriaca* Zone, which is indicative of a very late Devonian (lower *to*V) age.

Palmatolepis rugosa rugosa Branson and Mehl (11)
P. rugosa postera Ziegler (24)
P. rugosa subsp. undet. (15)
P. perlobata perlobata Ulrich and Bassler (1)
P. gracilis gracilis Branson and Mehl (3)
Icriodus sp. undet. (1)
Spathognathodus jugosus (Branson and Mehl) (6)
S. praelongus Cooper (9)
S. stabilis (Branson and Mehl) (5)
Polylophodonta sp. undet. (2)
Polygnathus perplexa Thomas (5)
P. triangularis Branson and Mehl (8)
P. semicostata Branson and Mehl (4)
P. granulosa Branson and Mehl *sensu* Thomas (14)
Pseudopolygnathus marburgensis Bischoff and Ziegler (1)

LOWER TONGUE OF COTTONWOOD CANYON MEMBER

Representative conodont collections from the lower tongue of the Cottonwood Canyon Member at three localities in Wyoming are listed in table 1. All three faunas are assigned to the lower *Spathognathodus costatus* Zone, which is indicative of a very late Devonian (upper *to*V) age. The fauna at Shoshone Canyon was collected from a 2-inch-thick lag sandstone at the base of the member (fig. 4, col. 5). The locality is at an elevation of about 5,800 feet on a prominent ridge on the north side of the canyon at the south end of Rattlesnake Mountain. It is in the W½SE¼NW¼ sec. 5, T. 52 N., R. 102 W., Park County, Wyo., in the Cody 15-minute quadrangle. The fauna at Cottonwood Canyon was collected from unit 3 of the type section of the member (fig. 5). It is the middle of three conodont collections dated *to*V (fig. 4, col. 6). The fauna listed for Dinwoody Canyon is from a combined sample that represents the upper 3 feet of the tongue except for the top 2 inches, which was sampled separately and was listed by Klapper (1966, table 1). The locality is at an elevation of about 6,870 feet just south of the trail on the north side of Dinwoody Canyon in the center NW¼NW¼ sec. 12, T. 4 N., R. 6 W., Fremont County, Wyo., in the Hays Park 7½-minute quadrangle.

TABLE 1.—*Representative conodont collections from the Lower* Spathognathodus costatus *Zone (upper* toV*) in the lower tongue of the Cottonwood Canyon Member in Wyoming*

[Shows number of identified specimens of indigenous (unreworked) conodonts]

Conodonts	Locality		
	Shoshone Canyon (fig. 4, col. 5)	Cottonwood Canyon (fig. 4, col. 6)	Dinwoody Canyon
Spathognathodus aculeatus	22	15	10
S. costatus costatus	2	----------	----------
S. stabilis	----------	21	9
S. praelongus	9	9	----------
S. jugosus	1	1	----------
Palmatolepis gracilis gracilis	9	6	5
P. gracilis sigmoidalis	4	3	----------
Icriodus costatus	11	18	11
I. constrictus	----------	----------	1
Polygnathus communis	2	31	11
P. symmetrica	7	----------	----------
P. delicatula	9	112	20
P. obliquicostata	----------	----------	27
Apatognathus varians	----------	16	1

UPPER TONGUE OF COTTONWOOD CANYON MEMBER

The upper tongue of the Cottonwood Canyon Member contains faunas assigned to three conodont zones—the *Siphonodella sulcata* Zone (lower *cu*I), the *S. sandbergi–S. duplicata* Zone (upper *cu*I), and the Lower *S. crenulata Zone* (*lower cu*IIα)—all of which are indicative of an Early Mississippian (Kinderhook) age. The oldest conodont faunas, those of the *S. sulcata* Zone, were found in three samples but at only one locality, near Windy Gap in the Washakie Range, Wyo. The collecting locality is at an elevation of about 8,200 feet on the north end of Black Mountain about 0.9 mile south of Windy Gap in the E½SW¼SE¼ sec. 36, T. 43 N., R. 106 W., Fremont County, Wyo., in the Indian Point 7½-minute quadrangle. The fauna, listed below, occurs in sample WG–1 from a 1-inch-thick bed in the middle of the basal 1 foot of the upper tongue of the member 16 feet above the base of the Madison Limestone.

Siphonodella sulcata (Huddle) (23)
Pseudopolygnathus dentilineata Branson (25)
Gnathodus n. sp. (13)
Polygnathus inornata Branson (5)

Polygnathus communis Branson and Mehl (218)
Spathognathodus aculeatus (Branson and Mehl) (61)
S. stabilis (Branson and Mehl) (24)
n. gen., n. sp. Rhodes, Austin, and Druce (1967, pl. 2, figs. 8–11)

The second sample (WG–20), which is from 2–6 inches below sample WG–1, contains virtually the same fauna including *Siphonodella sulcata* and *Gnathodus* n. sp., but it also has another species of *Gnathodus* comparable to *Gnathodus* n. sp. B of Collinson, Scott, and Rexroad (1962, chart 3). The third sample (WG–22), from 5–6 inches above sample WG–1, contains *S. sulcata* and the same *Gnathodus* n. sp. as sample WG–1.

The next to the oldest conodont faunas found in the upper tongue are assigned to the *Siphonodella sandbergi–S. duplicata* Zone. At Horse Creek and Warm Spring Canyon the basal lag deposit of this tongue contains conodont faunas that definitely are younger than faunas of the *S. sulcata* Zone at Windy Gap but probably are slightly older than the faunas assigned to the *S. sandbergi–S. duplicata* Zone at other localities.

The following fauna, which is considered to represent an older part of the *Siphonodella sandbergi–S. duplicata* Zone, was obtained from sample HC–7F of a ½-foot-thick highly glauconitic and phosphatic lag deposit at the base of the tongue at Horse Creek in the Washakie Range. The locality, which is only 5 miles northwest of the Windy Gap locality, is at an elevation of 7,660 feet in an abandoned quarry just south of the Horse Creek road in the SW¼SE¼ SW¼ sec. 19, T. 43 N., R. 106 W., Fremont County, Wyo., in the Ramshorn Peak 7½-minute quadrangle.

Siphonodella duplicata (Branson and Mehl) (25)
S. sulcata (Huddle) (1)
S. cooperi Hass (1)
S. obsoleta Hass (1)
Pseudopolygnathus dentilineata Branson (10)
P. prima Branson and Mehl (1)
Polygnathus communis Branson and Mehl (14)
P. inornata Branson (7)
P. symmetrica Branson (1)
P. longipostica Branson and Mehl (3)
Spathognathodus aculeatus (Branson and Mehl) (14)
Elictognathus lacerata (Branson and Mehl) (2)

From a cut of the same sample (HC–7F) from Horse Creek, J. W. Huddle (written commun., 1964) obtained and identified approximately the same fauna and also one specimen of *Gnathodus* sp.

The following poorly preserved fauna, which is tentatively considered to represent an older part of the *Siphonodella sandbergi–S. duplicata* Zone, was obtained from sample WS–1F of a 2-inch-thick lag deposit at the base of the tongue at Warm Spring Canyon in the Wind River Range. The locality, which is about 11 miles southwest of the Horse Creek locality, is just above creek level at an elevation of about 7,350 feet in the S½SW¼SW¼ sec. 31, T. 42 N., R. 107 W., Fremont County, Wyo., on the west edge of the Dubois 7½-minute quadrangle.

Siphonodella duplicata (Branson and Mehl) (1)
Siphonodella sp. undet. (9)
Pseudopolygnathus dentilineata Branson (1)
Polygnathus communis Branson and Mehl (1)
P. symmetrica Branson (1)
P. longipostica Branson and Mehl (1)
Spathognathodus aculeatus (Branson and Mehl) (3)

From a cut of the same sample (WS–1F) from Warm Spring Canyon, J. W. Huddle (written commun., 1964) obtained and identified the following fragmentary conodonts, which he stated do not appear to be waterworn like the bulk of the specimens:

Siphonodella sp. (4)
Pseudopolygnathus prima? Branson and Mehl (2)
Polygnathus communis Branson and Mehl (5)
Polygnathus inornata? Branson (8)

The upper tongue of the Cottonwood Canyon Member at most other localities yielded conodont faunas that are assigned to the *Siphonodella sandbergi–S. duplicata* Zone and are considered to represent the upper part of this zone. These faunas are very similar, as shown in table 2, which lists the major faunal constituents from one locality in Montana and five localities in Wyoming. The fauna at Baker Mountain was collected from the previously mentioned basal lag sandstone (fig. 4, col. 2) at an elevation of about 5,680 feet on the east end of Baker Mountain about 500 feet above the Boulder River road in the N½SW¼NW¼ sec. 35, T. 3 S., R. 12 E., Sweetgrass County, Mont., in the McLeod Basin 7½-minute quadrangle. The fauna listed for Shoshone Canyon, Wyo., was collected from the base of the upper tongue (fig. 4, col. 5) at an outcrop just above river level on the north bank of the Shoshone River about half a mile east of the location described for the fauna from the lower tongue at Shoshone Canyon. This upper tongue fauna also is present but is not as abundant at the location described for the lower tongue fauna. The fauna from the upper tongue at Cottonwood Canyon, Wyo., was collected from unit 5 of the type section of the member (fig. 4, col. 6; fig. 5). The fauna at South Fork Rock Creek was collected from the basal lag deposit of the upper tongue (fig. 4, col. 7) about 300 feet above the creek on its north side. The locality is in the NW¼SW¼ sec. 25, T. 52 N., R. 84 W., Johnson County, Wyo., on the Sheridan 1:250,000 Army Map Service sheet NL 13–10. The fauna listed for North Crazy Woman Canyon was collected from the basal lag deposit of the upper tongue about 30 feet above a dirt road on the north side of the canyon. The locality is in the NE¼NW¼SE¼ sec. 28, T. 49 N., R. 83 W., Johnson County, Wyo., as located on a geologic map of the Crazy Woman Creek area (Hose, 1955, pl. 6). The fauna from the upper part of the *S. sandbergi–S. duplicata* Zone at Windy Gap, Wyo., was obtained from sample WG–2, which was collected from the middle of the upper tongue and 0.3 to 0.7 foot above the highest bed containing the *S. sulcata* Zone at the same location.

TABLE 2.—*Representative conodont collections from the upper part of the* Siphonodella sandbergi–Siphonodella duplicata *Zone (upper* cu*l) in the upper tongue of the Cottonwood Canyon Member in Montana and Wyoming*

[Shows number of identified specimens of indigenous (unreworked) conodonts that occur at more than one locality]

Conodonts	Baker Mountain (fig. 4, col. 2)	Shoshone Canyon (fig. 4, col. 5)	Cottonwood Canyon (fig. 4, col. 6)	South Fork Rock Creek (fig. 4, col. 7)	North Crazy Woman Canyon	Windy Gap
Siphonodella sandbergi	6	--------	4	9	1	10
S. duplicata	5	6	--------	--------	--------	6
S. cooperi	17	12	1	9	2	26
S. obsoleta	8	--------	3	8	1	9
S. quadruplicata	7	6	1	14	5	36
Pseudopolygnathus dentilineata	34	32	1	7	--------	29
Polygnathus communis	9	18	6	7	1	10
P. symmetrica	1	1	3	4	5	------
P. inornata	17	9	3	71	24	77
P. longipostica	2	1	--------	6	4	19
Spathognathodus stabilis	2	--------	3	4	1	2
S. aculeatus	--------	3	--------	--------	2	31
Elictognathus bialata	4	--------	1	2	2	1
E. lacerata	2	--------	1	1	--------	3
Dinodus leptus	--------	--------	3	--------	--------	1

The following fauna, which also is assigned to the upper part of the *Siphonodella sandbergi–S. duplicata* Zone, was found within the upper tongue and 2.1–2.3 feet above the basal lag deposit (sample HC–7F) that contains the lower part of this zone at Horse Creek, Wyo.

Siphonodella sandbergi Klapper (10)
S. cooperi Hass (5)

S. obsoleta Hass (1)
Polygnathus communis Branson and Mehl (4)
P. inornata Branson (3)
P. longipostica Branson and Mehl (10)
Elictognathus bialata (Branson and Mehl) (3)
Dinodus leptus Cooper (2)

The following fauna, which is similar to those listed in table 2 and, hence, is also assigned to the upper part of the *Siphonodella sandberg–S. duplicata* Zone, was identified by J. W. Huddle (written commun., 1965). It was obtained from sample SH–3 of the upper tongue at a section measured by Sandberg (1967) at Shell Canyon (fig. 1), on the west side of the Bighorn Mountains. The locality (USGS 22243–PC) is at an elevation of about 4,760 feet on the north side of the canyon, on the opposite side of Shell Creek from U.S. Highway 14, in the SE¼SE¼SW¼ sec. 9 (unsurveyed), T. 53 N., R. 90 W., Big Horn County, Wyo., in the Black Mountain 7½-minute quadrangle.

Siphonodella sandbergi Klapper (31)
S. cooperi Hass (56)
S. obsoleta Hass (9)
S. quadruplicata Branson and Mehl (1)
Pseudopolygnathus prima Branson (7)
Polygnathus communis Branson and Mehl (10)
P. symmetrica Branson (20)
P. inornata Branson (170)
**P.* aff. *P. scobiniformis* Branson (15)
**Spathognathodus costatus* Branson (11)
**S.* spp. (many fragments)
Elictognathus bialata (Branson and Mehl) (2)
E. lacerata (Branson and Mehl) (2)
Dinodus fragosus Branson (4)

At some localities in Montana, the upper tongue of the Cottonwood Canyon Member contains well-preserved conodont faunas that are younger than any found in the tongue in Wyoming and as young as any found in the basal carbonate beds of the Lodgepole Limestone. These faunas are asigned to the Lower *Siphonodella crenulata* Zone (lower *cu*IIα), which indicates an Early Mississippian (Kinderhook) age.

The fauna in the following list was collected 5–9 inches above the base of the upper tongue at Meridian Ridge. It is the lower of two collections from the tongue dated as *cu*IIα (fig. 4, col. 3). The other collection, from 5.2–5.5 feet above the base of the tongue, does not contain as many conodont specimens but is similar in composition.

The locality is at an elevation of about 9,000 feet on the south side of the ridge that extends westward from Meridian Peak and forms the narrow divide between Pebble and Soda Butte Creeks about 1 mile northwest of the Northeast Entrance in Yellowstone National Park, in the N½SW¼ sec. 29, T. 9 S., R. 14 E. (unsurveyed), in the Cutoff Mountain 15-minute quadrangle, Mont.

Siphonodella crenulata (Cooper) (11)
S. cooperi Hass (55)
S. obsoleta Hass (23)
S. quadruplicata (Branson and Mehl) (44)
Pseudopolygnathus marginata (Branson and Mehl) (19)
P. dentilineata Branson (2)
Polygnathus communis Branson and Mehl (18)
P. symmetrica Branson (5)
P. inornata Branson (30)
P. longipostica Branson and Mehl (9)
**P. semicostata* Branson and Mehl (1)
Spathognathodus stabilis (Branson and Mehl) (71)
S. aculeatus (Branson and Mehl) (1)
S. crassidentatus (Branson and Mehl) (1)
Elictognathus lacerata (Branson and Mehl) (48)
**Palmatolepis rugosa* subsp. undet. (6)

At Bandbox Mountain a ½-inch-thick lag deposit, which may be related to the upper tongue of the Cottonwood Canyon Member, at the base of the Lodgepole Limestone yielded the following fauna, which also is assigned to the Lower *Siphonodella crenulata* Zone (lower *cu*IIα). The location of this collection is identical with that previously given for the collection from the Sappington Member of the Three Forks Formation at Bandbox Mountain.

Siphonodella crenulata (Cooper) (2)
S. cooperi Hass (2)
S. obsoleta Hass (1)
Pseudopolygnathus prima Branson and Mehl (1)
Polygnathus inornata Branson (1)
P. longipostica Branson and Mehl (1)

The following sparse poorly preserved fauna, which could not definitely be assigned to either the *Siphonodella sandbergi–S. duplicata* or Lower *S. crenulata* Zone, was collected from the upper tongue of the Cottonwood Canyon Member at Peak 9559, Mont., near the location described for the collection from the Trident Member of the Three Forks Formation there. In the absence of species that are diagnostic of only one of these zones, the fauna is dated as *cu*I–IIα (fig. 4, col. 1).

Siphonodella obsoleta Hass (1)
S. sp. undet. (5)
Polygnathus sp. undet. (1)
Spathognathodus sp. undet. (1)
Elictognathus lacerata (Branson and Mehl) (1)

MADISON LIMESTONE

The lower 10–25 feet of carbonate rocks in the undifferentiated part of the Madison Limestone (or Group) in areas of Wyoming where the Lodgepole Limestone is not recognized yielded conodont faunas assignable to two and possibly three conodont zones. Faunas assignable to the Lower *Spathognathodus costatus* Zone (upper *to*V) were found at Dinwoody Canyon and Windy Gap. Faunas assignable to the *Siphonodella sandbergi–S. duplicata* Zone (upper *cu*I) were found at Clarks Fork Canyon and Windy Gap. Faunas assignable to either the *S. sandbergi–S. duplicata* or the Lower *S. crenulata* Zone (upper *cu*I–lower *cu*IIα) were found at Bull Lake, Cottonwood, and Little Tongue Canyons.

The oldest of these conodont faunas, that of the Lower *Spathognathodus costatus* Zone, which is indicative of a very late Devonian (upper *to*V) age, is best displayed by five collections from the lower 16 feet of the Madison Limestone at Dinwoody Canyon. The location of these collections is identical with that given for the collection from the lower tongue of the Cottonwood Canyon Member at Dinwoody Canyon. As the intermediate three collections contain the same conodont species, only the representative faunas from the lowest and highest collections are listed.

The following very late Devonian (upper *to*V) fauna was obtained from the basal 4 feet of the undifferentiated lower part of the Madison Limestone, which overlies the Cottonwood Canyon Member, at Dinwoody Canyon.

Icriodus costatus (Thomas) (2)
Polygnathus delicatula Ulrich and Bassler (5)
P. obliquicostata Ziegler (18)
P. communis Branson and Mehl (14)
Spathognathodus praelongus Cooper (1)
S. stabilis (Branson and Mehl) (3)
Apatognathus varians Branson and Mehl (15)

The very late Devonian (upper *to*V) fauna in the following list was obtained from sample DW–13 collected by the senior author and J. F. Murphy 12–16 feet above the base of the undifferentiated lower part of the Madison Limestone at Dinwoody Canyon.

Icriodus costatus (Thomas) (3)
Polygnathus delicatula Ulrich and Bassler (4)
P. obliquicostata Ziegler (4)
P. communis Branson and Mehl (3)
Spathognathodus aculeatus (Branson and Mehl) (1)
S. stabilis (Branson and Mehl) (1)
Apatognathus varians Branson and Mehl (3)

As the Madison Limestone has long been regarded as entirely Mississippian in Wyoming, cuts of all five samples from Dinwoody Canyon were submitted to J. W. Huddle, whose identifications and age determinations closely match those of the authors. Only Huddle's faunal list from the highest sample (DW–13) is presented here, because its determination as Late Devonian precludes a Mississippian age for the four lower samples.

The following fauna was obtained and identified by J. W. Huddle (written commun., 1965) from sample DW–13 of the Madison Limestone at Dinwoody Canyon (USGS loc. 7574–SD).

Icriodus costatus (Thomas) (4)
Palmatolepis sp. (fragment)
Polygnathus obliquicostata Ziegler (5, small)
P. sp. (3)
Spathognathodus costatus Branson (3)
S. aculeatus (Branson and Mehl) (2)

In reference to this fauna, Huddle wrote:

The presence of *Icriodus* and *P. obliquicostata* indicates a Late Devonian age for this collection. *S. costatus* and *S. aculeatus* occur in Upper Devonian and Lower Mississippian rocks. If the Devonian forms are reworked (they do not look reworked but they could be), the fauna could be as young as Kinderhook and equivalent to faunas of the Hannibal or Chouteau Formation of the Mississippi Valley. I prefer a Late Devonian age (upper *to*V, Lower *Spathognathodus costatus* Zone) for this collection.

The following conodont fauna, which is assigned to the *Siphonodella sandbergi–S. duplicata* Zone, was obtained from a sample of the basal 1 inch of the undifferentiated part of the Madison Limestone that directly overlies the Cottonwood Canyon Member at the Clarks Fork Canyon, Wyo., reference section (fig. 4, col. 4).

Siphonodella sandbergi Klapper (4)
S. cooperi Hass (3)
Pseudopolygnathus dentilineata Branson (1)
Polygnathus communis Branson and Mehl (1)
P. inornata Branson (5)
P. longipostica Branson and Mehl (1)

The conodont fauna in the following list was obtained 19–22 feet above the base of the undifferentiated Madison Limestone and directly above the upper tongue of the Cottonwood Canyon Member at Windy Gap, Wyo. It is assigned to the *Siphonodella sandbergi–S. duplicata* Zone, although it may represent a very high part of that zone and possibly even the boundary with the overlying Lower *S. crenulata* Zone. Most of the conodonts listed are characteristic of the *S. sandbergi–S. duplicata* Zone. However, *Spathognathodus abnormis* has not been found below the Lower *Siphonodella crenulata* Zone elsewhere in the report area. The fauna was collected at the same location as that given for the faunas from the *S. sulcata* Zone at Windy Gap.

Siphonodella sandbergi Klapper (3)
S. cooperi Hass (1)
S. quadruplicata (Branson and Mehl) (2)
Polygnathus communis Branson and Mehl (8)
P. inornata Branson (4)
P. longipostica Branson and Mehl (4)
Spathognathodus abnormis (Branson and Mehl) (1)
S. crassidentatus (Branson and Mehl) (1)
Elictognathus bialata (Branson and Mehl) (1)
E. lacerata (Branson and Mehl) (2)
Dinodus leptus Cooper (1)

The following fauna was collected from the undifferentiated lower part of the Madison Limestone, 6 inches above the top of the Cottonwood Canyon Member, at Bull Lake Canyon. It may represent either the *Siphonodella sandbergi–S. duplicata* or Lower *S. crenulata* Zone. In the absence of conodonts that occur exclusively in either zone, the fauna is assigned a Kinderhook (upper *cu*I–lower *cu*IIα) age. The collection was made from an outcrop at an elevation of 5,900 feet just north of a trail at the base of the north wall of the canyon in the center SW¼SE¼ sec. 3, T. 2 N., R. 4 W., Fremont County, Wyo., as located on the geologic map of the Bull Lake West quadrangle (Murphy and Richmond, 1965).

Siphonodella sp. (1)
Polygnathus inornata Branson (2)
P. sp. (8)
Spathognathodus crassidentatus (Branson and Mehl) (2)
S. stabilis (Branson and Mehl) (1)

The following fauna was collected from unit 7 in the undifferentiated lower part of the Madison Limestone 5.1–5.6 feet above the top of the Cottonwood Canyon Member at its type section. This fauna also is assigned a Kinderhook (upper *cu*I–lower *cu*IIα) age.

Siphonodella obsoleta Hass (16)
S. quadruplicata (Branson and Mehl) (2)
Polygnathus communis Branson and Mehl (3)
P. inornata Branson (7)
P. longipostica Branson and Mehl (1)
P. symmetrica Branson (3)
Spathognathodus crassidentatus (Branson and Mehl) (2)
S. stabilis (Branson and Mehl) (1)
Elictognathus lacerata (Branson and Mehl) (1)

The following conodont fauna from Little Tongue Canyon (USGS loc. 22163–PC) was identified by J. W. Huddle (written commun. to W. J. Sando, April 19, 1966) from a sample of the undifferentiated lower part of the Madison Limestone, 5.6–6.6 feet above the top of the Cottonwood Canyon Member, collected by W. J. Sando. The authors consider this fauna to be comparable with that from the Madison at Cottonwood Canyon, 36 miles to the west, and to likewise represent a Kinderhook (upper *cu*I–lower *cu*IIα) age. The locality is in a roadcut on the north side of U.S. Highway 14 in sec. 27, T. 56 N., R. 87 W., Sheridan County, Wyo.

Siphonodella cooperi Hass (13)
S. obsoleta Hass (4)
Pseudopolygnathus sp. (4)
Polygnathus communis Branson and Mehl (2)
P. inornata Branson (10)
P. sp. (3)
Spathognathodus stabilis (Branson and Mehl) (6)
S. sp. (2)

LODGEPOLE LIMESTONE

The basal 10 feet of bioclastic crinoidal limestone in the undifferentiated lower part of the Lodgepole Limestone in Montana and western Wyoming yielded conodont faunas assignable to only one zone, the Lower *Siphonodella crenulata* Zone. These faunas are indicative of an Early Mississippian (Kinderhook) age, equivalent to a part of the *Pericyclus*-Stufe (lower *cu*IIα) of the Lower Carboniferous of Europe. Faunas assigned to this zone at nine localities in Montana and at one locality in Wyoming were listed by Klapper (1966, table 1). Table 3 lists representative faunas from the Lower *S. crenulata* Zone at the three localities in Montana that are shown on the cross section (fig. 4, cols. 1–3) and at the recently discovered Bandbox Mountain, Mont., locality. The collection at Peak 9559 is from the basal 1 foot of the undifferentiated Lodgepole, which directly overlies the Cottonwood Canyon Member, near the location of the collection from the

Trident Member of the Three Forks Formation there. The collection at Baker Mountain is from the basal 3 feet of the undifferentiated Lodgepole at the same location as the collection from the Cottonwood Canyon Member there. The collection at Meridian Ridge is from 2.1–2.6 feet above the base of the undifferentiated Lodgepole at the same location as the collection from the Cottonwood Canyon Member there. The collection at Bandbox Mountain is from 2.0–2.3 feet above the ½-inch-thick basal lag deposit of the Lodgepole or Cottonwood Canyon at the same location as the collection from the Sappington Member of the Three Forks there.

TABLE 3.—*Representative conodont collections from the Lower* Siphonodella crenulata *Zone (lower* cu*IIα) in the basal part of the undifferentiated Lodgepole Limestone in Montana*

Conodonts	Locality			
	Peak 9559 (fig. 4, col. 1)	Baker Mountain (fig. 4, col. 2)	Meridian Ridge (fig. 4, col. 3)	Bandbox Mountain
Siphonodella crenulata	35	7	4	4
S. cooperi	29	2	27	10
S. obsoleta	9	--------	5	42
S. quadruplicata	12	2	2	9
Pseudopolygnathus marginata	10	2	1	--------
P. triangula triangula	11	--------	--------	10
Polygnathus communis	7	1	10	17
P. inornata	7	2	19	5
P. longipostica	6	--------	2	--------
P. symmetrica	6	1	4	--------
Spathognathodus stabilis	4	--------	1	6
S. abnormis	--------	--------	--------	5
S. crassidentatus	5	1	1	--------
Elictognathus bialata	--------	--------	1	--------
E. lacerata	4	1	10	5
Falcodus angulus	1	--------	--------	5
Dinodus youngquisti	1	--------	--------	--------

PALEOTECTONIC INTERPRETATIONS

Deposition of the Cottonwood Canyon Member of the Madison (or Lodgepole) Limestone was closely related to and controlled by widespread paleotectonic events that occurred during Late Devonian and Early Mississippian time throughout western North America. The interpretations presented for the Cottonwood Canyon may be applicable to related lithologically similar clastic rocks that were deposited penecontemporaneously in shelf areas of western Canada and the central United States.

In the region encompassing the southern or United States part of the Williston basin and Northern Rocky Mountains, the earlier movements are interpreted as epeirogenic and the later movements as mildly orogenic. The epeirogenic movements were manifested at first by retarded subsidence of parts of shallow intracratonic basins in early Late Devonian (Frasnian) time, then by a gradual regression of the seas, followed by a short cessation of deposition on the cratonic shelf in late Late Devonion time. A brief but moderately widespread transgression by the Madison sea occurred locally as the orogenic movements were beginning. These later movements were manifested regionally by sporadic locally intense uplifts that occurred around the margins of the Williston basin. They began in very late Devonian (*to*V) time and culminated in earliest Mississippian time (Sandberg, 1960, 1961, 1964). As the orogenic movements lessened, a second and more widespread transgression by the Madison sea began. Both the epeirogenic and orogenic movements in the region of the southern Williston basin and Northern Rocky Mountains probably are related to and partly contemporaneous with the more intense movements of the Antler orogeny [5] in regions on the west and southwest in Idaho and Nevada.

Late Middle Devonian seas were restricted to a northward-trending Cordilleran miogeosyncline on the far west and to an embayment that extended southeastward from the miogeosyncline in Alberta to the intracratonic Williston basin in North Dakota; following this restriction, early Late Devonian seas transgressed the intervening cratonic shelf that included most of the report area. A western sea, in which the Maywood Formation was cyclically deposited, transgressed eastward with minor fluctuations from the Cordilleran miogeosyncline. At the same time an eastern sea, in which the Souris River Formation was cyclically deposited, transgressed westward and southwestward from the Williston basin.

After the eastern and western seas had coalesced in north-central and central Montana, an early Late Devonian sea, in which the Jefferson Formation (or Group) was cyclically deposited, transgressed southward and southeastward with major fluctuations and covered most of the Wyoming part of the report area. Anomalously thin deposition caused by retarded subsidence marked the onset of epeirogenic movements related to the Antler orogeny in areas such as the ancestral Cedar Creek anticline and an ancestral anticline near the present Poplar dome in eastern Montana and the ancestral Nesson anticline in North Dakota (Sandberg, 1964). The maximum transgression of the early late Devonian sea occurred near the close of deposition of

[5] The term "Antler orogeny" is here applied in a broad sense to all associated orogenic movements that took place during Late Devonian and Early Mississippian time, although in a stricter sense it might be used only for those that occurred on the east margin of the eugeosyncline.

the Jefferson. The thicker lower and middle parts of the Birdbear Member (or Formation) represent an episode of stillstand of a widespread clear well-aerated sea.

Between early and late Late Devonian time, epeirogenic movements initiated a withdrawal of the sea that is indicated by restricted marine deposits. Anhydrite is interbedded with dolomite in the upper part of the Birdbear Member (or Formation), and a moderately thick evaporitic sequence makes up the overlying Logan Gulch Member of the Three Forks Formation. This regression was ended in the middle of late Late Devonian time by a transgression during which limestone and shale of the Trident Member of the Three Forks Formation were deposited. The oldest conodont fauna (Famennian, *to*III–IV) recovered during the present investigation comes from the highest beds of the Trident, directly below a disconformity at the base of the Sappington Member.

Following deposition of the Trident Member, many local uplifts began sporadically around the margins of the Williston basin and in northwestern, central, and southwestern Montana and west-central Wyoming. In southwestern Montana, an erosion surface of low relief formed on the Trident (Sandberg, 1965, p. 15). Elsewhere in Montana and Wyoming, the Trident was deeply eroded or completely truncated.

As erosion diminished, the Sappington Member was deposited disconformably on the Trident Member in southwestern Montana. Although the Sappington is largely regressive, its deposition began with a brief marine transgression represented by its basal black shale, which contains very thin interbeds of lag sandstone. Conodonts from this lag sandstone positively date the lower part of the Sappington as very late Devonian (lower *to*V) Like the lower part of the Sappington, the lower parts of the Exshaw Formation in northwestern Montana and of the Bakken Formation in northeastern Montana and North Dakota were deposited penecontemporaneously in shallow basins interspersed among the areas of uplift during episodes of lessened orogenic activity.

While the Sappington Member was being deposited in an isolated regressive sea in southwestern Montana, the first moderately widespread advance by a Madison sea began in western Wyoming. Conodont faunas recovered from lag deposits at the base of the lower tongue of the Cottonwood Canyon Member date the start of this transgression as very late Devonian (upper *to*V), and recently discovered conodont faunas, on which work is still in progress, suggest that the transgression continued into the latest Devonian (*to*VI).

At least three embayments probably extended eastward from the Cordilleran miogeosyncline into Wyoming during the first transgression of the Madison sea. Evidence for their exact delineation was largely destroyed, however, by ensuing erosion and by reworking during a second transgression. Two of the embayments are roughly located in figure 1 as eastward-projecting lobes of the 5- and 10-foot isopachs of the Cottonwood Canyon Member in the Bighorn Mountains. Remnants of deposits in the northernmost embayment are shown in cross section (fig. 4). The other embayment probably extended eastward in west-central Wyoming through the area between Bull Lake Canyon and Windy Gap. This embayment is not indicated by the isopachs in figure 1 because only its basal clastic deposits are assigned to the Cottonwood Canyon. The upper deposits within this southern embayment were slightly silty to nonsilty carbonate rocks assigned to the undifferentiated lower part of the Madison Limestone, which yields a very late Devonian (upper *to*V) conodont fauna at Dinwoody Canyon and Windy Gap. Possibly latest Devonian (*to*VI) conodont faunas from beds in the lower part of the Madison in the Bighorn Mountains and Wind River Range are currently being investigated.

The more intense of the moderate movements associated with the Antler orogeny in the southern Williston basin and Northern Rocky Mountains occurred in a rather brief episode of earliest Mississippian time, following deposition of the lower tongue of the Cottonwood Canyon Member. Significantly, conodont faunas assignable to the earliest Mississippian *Siphonodella sulcata* (lower *cu*I) Zone, when these movements were maximal, have been recognized in the report area only at Windy Gap. Elsewhere in Wyoming a hiatus representing earliest Mississippian (lower *cu*I) as well as possibly part of latest Devonian (*to*VI) time is present in the lower part of the Madison Limestone or between the lower and upper tongues of the Cottonwood Canyon Member, as at its type section.

During the earliest Mississippian orogenic episode, the ancestral Central Montana uplift, an area 215 miles long from east to west and 75 miles wide, was elevated. Accompanying erosion removed as much as 300 feet of Upper Devonian rocks and locally, near the center of the uplift, truncated Devonian and Ordovician rocks and cut into Cambrian rocks. The area where pre-Devonian rocks directly underlie the upper tongue of the Cottonwood Canyon Member is shown in figure 2. In eastern Montana, east of the report area, the 125-mile-long northwest-plunging ancestral Cedar Creek anticline was uplifted, and its steep west flank was reversed faulted (Sandberg, 1961). Accompanying erosion stripped as much as 750 feet of Devonian and Silurian rocks from domes along the crest of this ancestral anticline. Minor uplifts related to these major uplifts probably took place sporadically throughout the region and within the report area. They are not as well defined because accompanying erosion only locally truncated exposed rock units.

While these movements were taking place, clastic sediments that formed the Sappington Member of the Three Forks Formation continued to be deposited in an isolated regressive sea in southwestern Montana. Silty sediments that formed the upper part of the Exshaw Formation and the medial part of the Bakken Formation were also laid down at about the same time in other regressive seas.

As erosion related to the orogenic episode diminished, the second major advance of the Madison sea began. This eastward transgression apparently occurred along the entire length of the Cordilleran miogeosyncline west of the report area and was not initially confined to embayments as was the first transgression. The basal lag deposits of the upper tongue of the Cottonwood Canyon Member were laid down on an irregular land surface, composed in the report area of earliest Mississippian to Late Cambrian rocks (fig. 2). The resulting unconformity is part of a major interregional unconformity that is widespread in the Western United States and Western Canada. Where the transgressive Madison sea engulfed the residual Sappington sea in southwestern Montana, however, no subaerial erosion occurred. There, the stratigraphic break at the base of the Cottonwood Canyon is inconspicuous, although generally marked by a very thin conodont-bearing lag sandstone that rests on unit 5 of the Sappington Member. In parts of Wyoming where the lower tongue of the Cottonwood Canyon previously had been deposited, a disconformity resulting from the short episode of erosion separates the two tongues.

That the second transgression of the Madison sea took place briefly in Early Mississippian time is proved by the lack of zonally significant diachronism in the basal deposits. The upper tongue of the Cottonwood Canyon Member and the lower undifferentiated part of the Lodgepole Limestone almost everywhere yield conodont faunas assigned to the upper part of the *Siphonodella sandbergi–S. duplicata* (upper *cu*I) and Lower *S. crenulata* (lower *cu*IIα) Zones, which together represent a short time span. Only in the Washakie Range and northern Wind River Range, Wyo., is there faunal evidence that the second transgression began, possibly as an embayment, slightly earlier in the Mississippian.

The geographic distribution and facies relations between the virtually synchronous bioclastic crinoidal limestone in the lower, undifferentiated part (or locally in the Paine Shale Member) of the

Lodgepole Limestone and the shale and siltstone facies and the dolomitic facies of the upper tongue of the Cottonwood Canyon Member have a definite pattern that can be explained paleotectonically. Their succession laterally from east to west and vertically both regionally and at some measured sections is dolomitic facies, shale and siltstone facies, and bioclastic limestone facies. The dolomitic facies occupies a north-trending belt east of the shale and siltstone facies (fig. 1). On the west it grades and intertongues upward into the shale and siltstone facies. The shale and siltstone facies, which is in turn overlain by the bioclastic limestone facies of the Lodgepole, occupies a medial belt. Farther west, along the west side of the report area, the shale and siltstone facies apparently thins to extinction and only the bioclastic limestone facies, which contains interbeds and laminae of black carbonaceous shale, is present. All three facies are believed to be transgressive deposits of an eastward-advancing Madison sea, although the shale and siltstone facies suggests an approach to stillstand.

The dolomitic facies contains abundant rounded glauconite grains, well-rounded quartz sand grains, and fish bones, plates, and teeth. Many of the fish bones are small broken fragments that were evidently rounded by abrasion. These constituents and the rarity of marine invertebrate fossils, such as corals and brachiopods, suggest that this facies was deposited in shallow turbulent water. Consequently, and particularly in view of its eastern paleogeographic position, the dolomitic facies is interpreted to represent littoral and marginal marine deposition.

The carbonaceous dolomitic siltstone of the shale and siltstone facies, like the dolomitic facies to which it is gradational, contains glauconite grains and scattered conodont and fish remains. The siltstone, however, contains marine palynomorphs and carbonized plant fragments, which are uncommon in the dolomitic facies. The carbonaceous shale contains more marine palynomorphs and macerated plant remains but fewer conodonts and fish remains than the siltstone. Both the shale and siltstone contain nodules of limonite, probably pseudomorphous after siderite, and nodules of quartz and hematite. Limonite is more common than glauconite in the shale and siltstone facies. Open-marine invertebrate fossils are generally scarce, but linguloid brachiopods are present. Crinoid columnals are abundant in the siltstone, particularly farther west, and bryozoans and conularids have been found locally in the shale. The environment of deposition of the shale and siltstone facies was less aerated and agitated than that of the dolomitic facies, but the depth of the water probably was as shallow. The sediments and their contents indicate reducing conditions that suggest a slight restriction of the sea and, hence, a lessening rate of transgression. The shale and siltstone facies is interpreted to be a lagoonal or mud-flat deposit in which many of the plant and animal remains were partly destroyed by burrowing organisms, as indicated by abundant worm trails and burrows at some localities.

The crinoidal debris in siltstone of the shale and siltstone facies probably originated elsewhere, as there is no probable source in the environment of deposition. It probably did not come from the east where the sandy and silty dolomitic facies was being deposited, because crinoid fragments are relatively scarce in that facies. Hence, if probably came from the west.

Unconsolidated deposits related to the bioclastic limestone facies, which generally forms the basal 2–15 feet of the Lodgepole Limestone, may have served as the barrier that partly restricted the waters in which the shale and siltstone facies was laid down. These deposits may also have provided a source for some of the crinoidal debris found in siltstone of that facies. Such a barrier could have been in the form of discontinuous banks of crinoidal debris parallel to the shoreline and not much higher than 10–15 feet above the sea bottom. Some of these banks, in fact, may have been much higher. Biostromes as much as 150 feet high are recognized in the Lodgepole along the western limit of the shale and siltstone facies of the Cottonwood Canyon Member in the Big Snowy Mountains, Mont. (fig. 1). More detailed study in southwestern Montana and western Wyoming may reveal the presence of similarly high biostromes in the Lodgepole farther south along this same limit.

The bioclastic limestone facies contains abundant glauconite and open-marine invertebrate fossils and was laid down as a transgressive deposit in shallow well-aerated water. As the Madison sea transgressed farther eastward, the bioclastic limestone facies was deposited over the shale and siltstone facies. Although the bioclastic limestone facies has not been recognized above the dolomitic facies of the Cottonwood Canyon in central Wyoming, it is present above the Bakken Formation in the southern Williston basin of northeastern Montana and North Dakota.

As the Madison sea eventually covered the entire report area as well as the entire region of the Northern Rocky Mountains and southern Williston basin, deposition of thick beds of carbonate became widespread. The resulting Madison Group, which is as much as 2,800 feet thick in the central Williston basin, completely buried the latest Devonian to earliest Mississippian ancestral structural features and now dwarfs the thin but paleotectonically important transgressive deposits at its base.

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