THE DEVONIAN SYSTEM IN WESTERN WYOMING
AND ADJACENT AREAS

DISSERTATION

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the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

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INTRODUCTION

Purpose and Scope

The purpose of this study is to determine the regional stratigraphic relations of Devonian rocks in western Wyoming, southwestern Montana, eastern Idaho, and northeastern Utah.

Although the investigation is primarily on the Jefferson Formation of Late Devonian age, associated units are also discussed. These include the Maywood, Derby, Three Forks, and Beirness Formation, and a dark shale unit of Devonian and Mississippian age.

The most important information evolving from the study concerns the stratigraphic relations between the Jefferson and Three Forks Formations of Montana and the Darby Formation of west-central Wyoming.

Most of the area (Fig. 1) was a widespread shelf in Late Devonian time that extended from the eastern Dakotas to western Montana and western Wyoming. A miogeosyncline occupied the western portion of the area. Latest Devonian erosion restricted the eastern and southern extent of Devonian rocks. The shelf area lies west and south of the central Montana uplift and north of the Uinta arch, and includes the Tendoy dome along the Idaho-Montana border. The locations of the 75 sections measured by the writer are shown in Figure 2, and information on localities is summarized in Table 1.
Fig. 1. Index map showing location of area
Fig. 2. Physiography and locations of sections
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Previous Work

Numerous Devonian sections have been reported in connection with areal mapping projects, but few detailed descriptions and regional correlations have been made. The areas covered by recent stratigraphic work, in connection with petroleum exploration, are shown in Figure 3.

Sandberg and Hammond (1958) named and described Devonian units in the subsurface of the Williston basin and correlated the units with strata in central Montana. Sandberg (1961a) extended Devonian correlations into northern Wyoming. The thickness and extent of similar units on the Sweetgrass arch was shown by Hurley (1962). Classic Devonian sections near Three Forks, Montana, and southward to Yellowstone Park were studied by McMannis (1962). Devonian relations in southwestern Montana and east-central Idaho were summarized by Scholten and Hait (1962). Pre-Three Forks stratigraphy across the miogeosyncline in east-central Idaho was described by Churkin (1962).

Earlier work by Gloss and Laird (1945, 1946, 1947) resulted in the naming and correlation of several Devonian units in central and northern Montana. A regional stratigraphic study using these units was made by Andrichuk (1951). Subdivisions in the Williston basin and central Montana were recognized in northern Montana by Wilson (1955). Several Devonian sections in west-central Wyoming were correlated by Strickland (1957).
Fig. 3. Areas of recent stratigraphic work
Methods of Investigation

Field work during the summers of 1962 and 1963 involved the
detailed measuring of about 75 sections, the collecting of fossils
and rock samples, and plotting the data on strip logs for lithologic
correlation. Sections were measured with a six-foot steel tape when
possible, and by a hand level when necessary. Information was
recorded on a portable transistor tape recorder and was later
transcribed. Sections were measured from the underlying system
(Cambrian, Ordovician, or Silurian) to the Mississippian Madison
Limestone. An additional 25 sections have been included that were
described in detail by other workers. Well logs from the Green River
basin were donated by the American Stratigraphic Company. Detailed
information on each section is given in the Appendix.

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David Cole worked as a field assistant in 1962, and my wife, Barbara, assisted the following summer. The National Science Foundation granted a Summer Fellowship for Graduate Teaching Assistants for the summers of 1962 and 1963.

Nomenclature

The present state of Devonian nomenclature and correlation in the Northern Rocky Mountains and adjacent regions is illustrated in Figure 4.

The "classic" Devonian units, originally named by Peale (1893) in west-central Montana, are the Jefferson Formation and the Three Forks Formation. The Duperow (lower) Member and the Birdbear Member of the Jefferson were named by Sandberg and Hammond (1958). A basal Upper Devonian unit, called the Maywood Formation, underlies and is gradational with the Jefferson Formation. The Three Forks formation was divided by Sandberg (1965) into the Logan Gulch (evaporitic), Trident (green shale), and Sappington (sandstone) Members. Underlying the Mississippian Madison Limestone is a thin dark shale unit of Devonian and Mississippian age, named informally by Sandberg (1963b).

The Jefferson and Three Forks Formations of western Wyoming are similar to the sections in southwestern Montana. In west-central Wyoming the Devonian section is represented only by the Darby Formation, which is equivalent to the Lower Member of the Jefferson Formation. Channel-fill deposits equivalent to the Maywood Formation, and others equivalent to the Lower Devonian Beartooth Butte Formation occur locally in northern Wyoming.
Fig. 1. Regional correlation chart of the Devonian System.
In northeastern Utah and southeastern Idaho, Devonian rocks thicken westward into the miogeosyncline. The Jefferson Formation is easily recognized. A Lower Devonian unit called the Water Canyon Formation underlies the Jefferson. The lithologic equivalent of the Three Forks Formation is termed the Beirdneau Formation. The Leatham Formation locally overlies the Beirdneau, and a thick dark shale lies below the Mississippian Lodgepole Limestone.

Although the nomenclature applied to Devonian rocks on the Sweetgrass arch and in the Williston basin (Fig. 4) differs slightly from that in the area of this report, regional lithologic correlations have been made.
MAYWOOD FORMATION

Previous Work

The Maywood Formation is a detrital transgressive basal unit of Late Devonian age found mostly in western Montana. It was named by Emmons and Calkins (1913) for 200 to 300 feet of poorly exposed rocks at Maywood Ridge on the south side of Boulder Creek, about 12 miles northeast of Philipsburg, Montana. These rocks were designated as lying above the Cambrian Red Lion Formation and below the Jefferson Formation.

Detrital beds between the youngest Cambrian carbonates and the Jefferson Formation have been included by some in the Cambrian Dry Creek Shale. Sloss and Laird (1947) recognized that this detrital unit at most localities belongs to the Devonian cycle of sedimentation, for they found it lying on Ordovician strata farther east. As Lochman (1950) points out,

...most of the beds referred to in the literature by Weed, Deiss, and Lochman and Duncan as the Dry Creek shale are actually the basal Devonian unit and beds of undetermined age of Sloss and Laird and should be known as the "Maywood Formation."

The Red Lion Formation (Upper Cambrian) and the Maywood Formation are often mapped together as a single unit even though they are separated by an erosional unconformity. The two formations are similar in rock types and at many places form a single slope-forming unit.
The informal designation of unit C was proposed by Sloss and Laird (1947) for similar but thicker basal Upper Devonian beds in northwestern Montana. Because the term Maywood was the first name proposed, Lochman (1950) suggested that the term be used in central, western, and northwestern Montana. In eastern and northeastern Montana, the term Souris River Formation (Sandberg and Hammond, 1958, p. 2310) is used for basal Upper Devonian detrital rocks deposited from a sea transgressing west and south from the Williston basin.

The thickness and distribution of the Maywood in west-central Montana has been illustrated by McMannis (1962, Pl. X). Detailed information within the Three Forks quadrangle was presented by Robinson (1963). A Maywood channel fill near the southern edge of Maywood deposition in Montana was described by Sandberg and McMannis (1964). A similar channel fill in northern Wyoming was described by Sandberg (1963a). The thickness and distribution of the equivalent Souris River Formation in northern and northeastern Montana was illustrated by Hurley (1962) and Sandberg (1961a).

Description

The Maywood Formation consists mostly of dolomitic siltstone and silty and argillaceous dolomite, with minor mudstone, dolomite, and limestone. Sandstone predominates at the base in western Montana. The dolomite is commonly dense, non-fetid, and light-colored; it weathers buff. In west-central Montana the lower half is generally reddish and contains much detrital material. Three units were differentiated by Sandberg and McMannis (1964) in
west-central Montana, including lower and upper slope-forming units and a middle ledge-and-slope unit.

The formation rests disconformably on rocks of Cambrian and Ordovician ages. Lochman (1953) states that the boundary with underlying Cambrian rocks "should be drawn at the top of the highest shales or pebble conglomerates in which fossils or traces of fossils can be found."

The contact with the overlying Jefferson Formation is gradational and rises stratigraphically eastward. In western Montana, the contact is clearly transitional and is placed at the base of the lowest thick dark-colored fetid Jefferson carbonate. Further east where the Maywood is much thinner the contact is generally sharper.

Regional Distribution

**General statement.** The Maywood Formation is most readily recognized and thickest in western Montana. It was spread eastward from western Montana as a basal detrital unit of Late Devonian age. Channel-fill deposits equivalent (?) to the Maywood Formation occur as far southeast as central Wyoming. The southern limit of the Maywood in Montana extends westward from Livingston to Dillon. This basal detrital unit may possibly be present as a thin sandstone west of the Tendoy dome and may possibly extend into central Idaho.

**Western Montana.** At Maywood Ridge 300 feet of the Maywood Formation underlies the Jefferson Formation (Fig. 21). A thick dolomitic sandstone containing indeterminate fish plates is overlain by silty light gray dolomite. The upper half is light gray
argillaceous dolomite alternating with dark gray limestone and dolomite characteristic of the Jefferson. The basal dolomitic sandstone is present throughout western Montana (Fig. 5). It is well-exposed along the East Fork of Rock Creek southwest of Philipsburg where it consists of 70 feet of buff to pinkish dolomitic cross-bedded quartzite. The basal sandstone crops out in many places whereas the overlying Maywood strata are generally non-resistant.

West-central Montana. The Maywood changes thickness rapidly in the Three Forks quadrangle, according to Robinson (1963). The isopach map (Fig. 5) suggests deposition on a highly dissected pre-Maywood erosion surface. In the Three Forks area, Logan area, Bridger Range, and southern Elkhorn Mountains (Fig. 2) the Maywood ranges from 40 to 80 feet in thickness and can be divided into two parts. The lower half is generally reddish dolomitic siltstone and the upper half is buff-colored argillaceous dolomite. The basal red coloration may be due to weathering and reworking of underlying Cambrian carbonates.

Sandberg and McMannis (1964) divided the 56-foot Maywood section at Milligan Creek near Three Forks into three parts: a lower 25-foot silty dolomite, a middle 20-foot unit with four ledges of dolomitic limestone separated by silty intervals, and an upper 11-foot unit of silty calcareous dolomite. The middle unit contains Late Devonian brachiopods and other fossils indicative of an open marine environment. Salt casts in the lower unit suggest restricted circulation,
At Camp Creek south of Butte, Montana, the lowest thick dark-colored dolomite is used as the base of the Jefferson, although thin light-colored argillaceous Maywood-type dolomites occur at higher intervals.

**Southwestern Montana.** The Devonian System laps over the Tendoy dome in southwestern Montana. Sloss and Moritz (1951, p. 2149) state that in places a few inches to a few feet of reddish dolomitic shale occur at the base of the Devonian, but that Jefferson carbonates appear nearly in contact with older rocks below the unconformity. Sloss and Moritz made no attempt to distinguish a "basal Devonian unit" or Maywood Formation in southwestern Montana. Basal detrital strata are absent in sections measured by this writer in the Tendoy, Blacktail, Snowcrest, and Centennial Ranges (Fig. 2) in southwestern Montana.

**East-central Idaho.** In the Beaverhead Range, Scholten and Hatt (1962) found basal Upper Devonian sandy or conglomeratic beds and carbonate breccia from 2 to 26 feet thick. In the Lemhi Range at Spring Mountain Canyon they found a 100-foot channel-fill deposit containing fish fragments. A similar channel fill was found by Churkin (1962) at Badger Creek in the same range, but both deposits may be of Lower Devonian age. In the Lost River Range farther west, a detrital zone at the base of the Jefferson is reported by Churkin. The eastern limit of this detritus, probably equivalent to the Maywood Formation, is shown in Figure 6.

**Southeast Idaho, Utah, and Nevada.** Lower Devonian detrital rocks, named the Water Canyon Formation by Williams (1948) underly the Jefferson Formation in most of this area. It consists mostly
of buff-weathering dolomitic sandstone and silty dolomite, and contains an Early Devonian fish fauna. This formation is an eastern near-shore facies of most of the Sevy Dolomite described by Osmond (1962). The eastern limit of these Lower Devonian rocks is shown in Figure 6.

In east-central Nevada, Johnson (1962) concluded that the "Sevy sand," placed in the upper part of the Sevy Dolomite by Osmond (1954), is the basal deposit of a later marine advance. The "Sevy sand" lies disconformably on the main body of the Sevy Dolomite and may be continuous with basal Jefferson detritus around the north end of the Northwest Utah high (Fig. 6). East of Nevada, the "Sevy sand" is not prominent and the fossil break recognized by Johnson is difficult to observe for lack of fossils. Basal Jefferson detritus has been reported by Beus (1965) from the Blue Spring Hills on the Idaho-Utah border.

**Southern Montana.** A thin discontinuous light-colored conglomeratic silty and argillaceous dolomite underlies the Jefferson Formation in the northern part of the Madison and Gallatin Ranges and in the Beartooth Mountains. Although in most places less than 10 feet thick, these beds have sometimes been referred to the Maywood Formation; they constitute a thin time-transgressive basal detrital unit, but they may not be laterally continuous with the Maywood Formation. Accompanying the southeastward thinning and stratigraphic rise of Maywood-type strata is an increase in thickness of the underlying Ordovician Bighorn Dolomite.
Fig. 6. Distribution of Lower Devonian and basal Upper Devonian detrital rocks
The zero isopach of the Maywood Formation (Fig. 5) approximates the southern edge of Maywood deposition. This southern edge extends from Livingston, Montana, west-southwest toward Ennis and Dillon, Montana. Maywood rocks thin and may disappear over local highs north of this line. Southward the rocks pinch out into localized stream channel and/or estuarine deposits. Thickening toward the northwest into the marine Maywood may be partly the result of deposition in coalescing channels of a pre-Maywood drainage system as suggested by the isopach map (Fig. 5).

A channel-fill deposit was located by McMannis (1962) at Squaw Creek on the west side of the Gallatin Range. The rock sequence was divided into three units by Sandberg and McMannis (1964) and correlated with a similar sequence at Milligan Canyon, 35 miles northwest. This Late Devonian channel fill was deposited by marginal marine brackish or fresh waters in a wide, shallow estuary or bay. Continued marine transgression southeastward through this channel allowed deposition of normal marine carbonates of the Jefferson Formation. At least 74 feet of Cambrian rocks were removed at the channel locality, but the maximum Maywood thickness is 34 feet. Approximately 40 feet of the Jefferson Formation is restricted to the channel and accounts for the locally erratic thickness of the Jefferson.

**Wyoming.** An early Late Devonian channel fill crops out at Cottonwood Canyon in the Bighorn Mountains 30 miles southeast of the main body of the Maywood Formation (Fig. 6). Spirorbis limestone and silty dolomite described by Sandberg (1963a) were deposited in a
long estuary extending southeast from the main area of Maywood deposition. Similar Maywood strata may be present locally in the Pryor Mountains and northern Bighorn basin.

Channel-fill outcrops of Maywood (?) equivalents occur along the flanks of the Wind River Mountains. At Bull Lake Canyon is a 17-foot channel fill of dolomitic siltstone with abundant Bothriolepis (Benson, Murphy, and Sandberg, in preparation). Along the East Fork of DuNoir River (Fig. 14) is 20 feet of argillaceous silty and arenaceous dolomite containing abundant fish plates, pebbles, and carbonaceous material directly below normal Jefferson dolomite. East and west of this section these basal beds are missing. The fish plates were identified as Bothriolepis of probable Late Devonian age by D. H. Dunkle (C. A. Sandberg, written communication, Feb. 5, 1964).

On Sheep Mountain, in the northern Wind River Mountains, is a 20-foot section at the base of the Devonian rocks which contains argillaceous and arenaceous dolomite with rounded Bighorn pebbles in the lower six feet. This unit corresponds in lithology and position to the Maywood (?) equivalents at Bull Lake Canyon and DuNoir River and also to widespread detrital units in the lower part of the Jefferson to the west (Fig. 15). This suggests uniform encroachment of Late Devonian seas eastward to west-central Wyoming, at which point the earliest deposition was in estuarine reaches which had been cut in the Bighorn Dolomite. Although the lithology is similar, this channel fill may not be directly related with Maywood deposition in southern Montana. Basal detritus is present in a few other sections in western Wyoming, but is generally less
than five feet thick. At several localities the Jefferson carbonates rest directly on older rocks.

The channel fills at Bull Lake and DuNoir River were separated by an area of slight relief at the start of Late Devonian deposition. This is here called the Dubois dome (Fig. 6).

Relation to Lower Devonian Rocks

Upper Devonian channel-fill deposits appear to be localized in areas of the Lower Devonian Beartooth Butte Formation (Fig. 6). This formation was named and described by Dorf (1934) for an estuarine channel-fill deposit of reddish dolomite and dolomitic conglomerate outcropping on the east face of Beartooth Butte in northern Wyoming. An Early Devonian age was assigned on the basis of flora and fauna. The occurrence of Beartooth Butte channel fills and sinkhole deposits (Fig. 6) has been reported by Sandberg (1961b). Late Devonian Maywood (?) equivalents form only channel-fill deposits.

Close association of Upper and Lower Devonian detrital rocks can be noted at Cottonwood Canyon and Bull Lake Canyon, Wyoming, and Livingston Peak, Montana, and can be expected elsewhere. The two deposits generally cannot be distinguished except by paleontologic methods.

The Beartooth Butte deposits are restricted to northern Wyoming and southern Montana, but may have been more widespread prior to Middle Devonian erosion. Equivalent Lower Devonian Sevy-Water Canyon strata occur in southern Idaho and northern Utah, but there is no evidence of a former connection with the Beartooth Butte Formation.
Age

Brachiopods from limestone beds that lie 12 to 16 feet below the top of the Maywood near Milligan Creek in the Three Forks quadrangle are believed by A. J. Boucot (in Robinson, 1963) to be probably Late Devonian in age. Sandberg and Hammond (1958, p. 2313) add that these are early Late Devonian brachiopods, identified as *Spirifer* cf. *S. engelmanni* Meek, and spiriferid brachiopods of the *Allanaria-Eleutherokomma* type. A widespread faunal zone was noted by Wilson (1956) in the lowermost Duperow Formation and uppermost Souris River Formation in northern Montana which contains abundant *Allanaria-Eleutherokomma* spiriferid brachiopods. Brachiopods from the upper part of the Maywood in the southern Elkhorn Mountains, Montan, were identified by C. A. Cooper (in Klepper, et al., 1957, p. 13) as probably early Late Devonian.

A conodont fauna from black shales near the base of the Maywood equivalent in northwestern Montana was described by C. L. Cooper (1945). This fauna includes a preponderance of forms like those of Senecan age from the lower New Albany shale of Indiana and the Rhinestreet shale of New York. This establishes an early Late Devonian age (equivalent to the European Frasian stage) for the Maywood equivalent in northwestern Montana.

Fish plates collected from basal Devonian channel fills in southern Montana and northern Wyoming are *Bothriolepis* sp., and permit a probable early Late Devonian age designation.
JEFFERSON FORMATION

The term "Jefferson limestone" was first used by Peale (1893) to describe 640 feet of black and brown limestone and dolomite that underlies the Three Forks "shales" and overlies Cambrian limestone. A specific type section was not designated, but Peale sketched the exposure on the north side of the Gallatin River near Logan, Montana, where Sloss and Laird (1947) later established the type section. A detailed account of the standard surface section at Logan was presented by Sandberg (1962).

Early work on the extent and age of the Jefferson, by Kindle (1908), prompted recognition as far south as northeastern Utah. The Jefferson Formation, consisting mostly of dark-colored pre-dominantly carbonate rocks of Late Devonian age, is recognized by the writer throughout Montana, western Wyoming, eastern Idaho, and northeastern Utah. In the latter area, the name has also been used for the entire Devonian sequence, including rocks overlying the typical Jefferson Formation.

The Jefferson Formation of Sloss and Laird (1947) included overlying "breccias and associated shales." These rocks form the lower part of the slope-forming Three Forks Formation, and sharply overlie thick massive dolomite at the top of the Jefferson Formation.

A Lower Member and a Birdbeak (upper) Member, which can be recognized on the shelf area of Montana and western Wyoming, are...
discussed separately. The Birdbear Member was removed by latest Devonian erosion in west-central Wyoming, whereas the Lower Member extends eastward and forms the Darby Formation. The thick dark miogeosynclinal dolomite of the Jefferson Formation in Utah, Idaho, and western Montana cannot be subdivided. These rocks are discussed last under "Jefferson Formation undifferentiated." Areal distribution of the two members is shown in Figure 7, and total thickness of the Jefferson Formation in Figure 8.

**Lower Member**

**Previous Work**

The lower part of the Jefferson Group in the Williston basin was named the Duperow Formation by Sandberg and Hammond (1958). A standard subsurface section was designated between the depths of 10,400 and 10,743 feet in the Mobil Producing Company's Birdbear Well No. 1. This definition of Duperow gained widespread use, especially in the Williston basin. The Duperow Formation was traced by Sandberg and Hammond, and later by Sandberg (1961a), from the Williston basin into the outcrop area of west-central Montana and northern Wyoming. Additional work by Wilson (1955), McMannis (1962), Hurley (1962), and the writer shows that this lower part of the Jefferson is persistent and recognizable from the eastern Dakotas to western Montana, northward into Canada, and southward into Utah. The term Duperow is generally confined to the subsurface. Equivalent rocks in the outcrop area are generally too thin to be mapped separately and are regarded as a member of the Jefferson Formation.
Fig. 7. Fence diagram of Jefferson Formation
Fig. 8. Isopach map of Jefferson Formation
Because further subdivision might be feasible, the Lower Member remains unnamed in much of the outcrop area.

Description and Petrography

The Lower Member of the Jefferson Formation consists mainly of dolomite and limestone. Minor interbeds of detrital material become thicker and more numerous toward central Wyoming.

The dolomite is generally brownish gray to dark brown or dark gray, sacchroidal, and fine-to medium-crystalline. Bituminous material, in the form of interstitial or pelletoid hydrocarbons, causes the dark color and characteristic odor. Most of the dolomite is thick-bedded and ledge-forming. Wavy laminations, mostly due to algal banding, are common. Fossils include abundant Amphipora and other stromatoporoids and algal stromatolites which are responsible in many places for vuggy cavities on weathered surfaces.

The limestone is generally dark gray to brownish dark gray, dense, very finely crystalline, and less porous and permeable than the dolomite. Limestone, where present, is generally in the lower half of the Lower Member. Bituminous matter and fetid odor are characteristic. A variety of fossils, including some brachiopods, is present locally.

Thin detrital interbeds consist of shale, mudstone, siltstone, sandstone, and argillaceous, silty, and sandy carbonates. The detrital interbeds are most common in Wyoming, whereas to the west and northwest only the upper half of the Lower Member contains many persistent detrital slope-forming units. The occurrence of detrital interbeds
reflects cyclic deposition. Most of the associated non-detrital carbonates are dense, very finely crystalline, and light-colored.

Beds of limestone breccia that occur with the detrital units are interpreted as collapse breccias formed by solution of evaporite near the surface. The pseudobrecciated appearance of some dolomite beds may be caused by solution and subsequent collapse of minor amounts of anhydrite. Infrequent conglomerate beds are perhaps a result of local reworking.

In the shelf area the Jefferson is normally brownish gray or brown, whereas in the miogeosyncline farther west it is commonly dark gray. Immediately adjacent to intrusions the Jefferson is bleached to a light color. This color difference was noted and described by Robinson (1963), who believes the hydrocarbons were distilled near the heat source and condensed farther away where they impart a dark color to the rock.

A laterally persistent zone of mottled limestone occurs near the middle of the Lower Member in west-central Montana and in the thrust belt of western Wyoming. The groundmass is dark gray very finely crystalline dense limestone that contains branching seams of lighter-colored more coarsely crystalline dolomite. Dolomitization generally followed bedding planes, but in many places cut across them at right angles. The margin of dolomitization is sharp and the dolomite stands out in relief on weathered surfaces. This mottling is similar to the even-laminated variety described by Osmond (1956) in the Devonian Simonson Dolomite of eastern Nevada. Depositional control suggests an early diagenetic origin for the incomplete dolomitization
similar to that described by Beales (1953) for the Devonian Palliser Limestone in western Alberta. Rocks above this mottled zone in the Jefferson are nearly all completely dolomitized. Rocks underlying the mottled zone are limestone in most places except where later secondary dolomitization has occurred.

On the outer edge of the shelf and in the miogeosyncline the dolomite beds are laminated, primarily as a result of changes in grain size and amount of bituminous matter. These laminations probably originate from algal deposition and subsequent differential dolomitization.

The dark bluish gray dolomite of the miogeosyncline is irregular in texture under the microscope according to Ross (1947), but many crystals are euhedral. Petrographic work by Andrichuk (1956) showed that the sandy intervals have a bimodal size distribution. The larger grains are well rounded, the smaller grains are subangular to sub-rounded. Similar sandy intervals examined by Ross (1947) are mostly quartz, but contain some microcline.

Chemical analyses by Ross (1947) show that the dark portion of the Jefferson contains more organic matter than pre-Devonian dolomites or light-colored dolomite within the Jefferson Formation. The latter contained a significant amount of inorganic residue as compared to the dark Jefferson dolomites.

Although dolomitization has destroyed most of the original sedimentary features, work on unaltered limestone and relict features in dolomite by Lewis and Elliott (1962) resulted in the description of five original depositional types of limestone. A basinal limestone
(1) consists of fragmented fossils in a dense argillaceous limestone matrix. Biothermal limestone (2) consists mostly of algae, Amphiopora and other stromatoporoids, with algae generally serving as a framework binder. Leeward of the reefs are clastic limestones (3) (calcilutite, calcarenite, and calcirudite) mixed with lime mud (4). Oolites and pisolites (5) formed in strongly agitated shallow water. Lime muds and pelletoidal carbonates are believed to be lagoonal.

Petrography of the Duperow (Lower Member) in western North Dakota is described by Rich and Fernichle (in press). A similar study which includes Jefferson rocks in the western Teton Mountains is presented by Dixon and Reeves (in press).

Intraformational Correlation

Interpretation of regional stratigraphic relations of the Lower Member depends upon detailed intraformational correlation. Lateral persistence of units in the Jefferson has not been recognized and no previous attempt at detailed correlations has been made in the outcrop area. As an example of lateral variability, Anrichuk (1956) notes the differences in Devonian sections described by previous workers at Glory Mountain and Taylor Mountain, only a few miles apart in the southern Teton Range.

The change in thickness and lithologic aspect between these nearby sections illustrates the high variability of the Darby section and indicates the lensing character of the clastic and carbonate units.

Measurements by this writer indicate that these two sections are remarkably alike except in degree of exposure. The Lower Member differs
by only 10 feet in thickness in the two sections and rock types are
similar. The lateral persistence of units in the Lower (Duperow)
Member in the subsurface has been noted.

The limestone-dolomite division of Sloss and Laird (1947) falls
within the Lower Member, but can be applied in correlation only in
certain areas. The Lower Member in northern Wyoming can be divided
and correlated on the basis of thick carbonate ledges according to
Sandberg (1965). More detailed subdivision of the Lower Member using
detrital and ledge-forming units is illustrated by Benson, Murphy,
and Sandberg (in preparation) within the Darby Formation of west-central
Wyoming. In this paper the main methods of intraformational correlation
are detrital interbeds, carbonate ledges, limestone and dolomite
sequences, and fossil beds.

The Jefferson does not change much laterally and cannot be
depicted accurately on lithofacies maps of small areas. Isopach maps,
cross sections, and maps showing percentage of detrital and sand-
bearing beds are more useful.

**Detrital interbeds.** Detrital interbeds, even though thin and poorly
exposed, are useful for intraformational correlation within the Lower
Member. These beds occur at intervals throughout the Lower Member
from the eastern edge of Devonian rocks in Wyoming to western Montana.
In extreme western Montana and in Idaho, these detrital beds are thin,
few, and inconspicuous. The beds thicken and increase in number
southeastward toward the Late Devonian shoreline in central Wyoming.
The detrital units are lettered A through I in descending order from the top of the Lower Member. A, B, C, and D are the most persistent. Detrital unit A is the thickest (8 to 24 feet) and can be traced from the Williston basin to northeastern Utah. This same detrital interval was found at the top of the Duperow across northern Montana where it is called the gray-green shale marker by Hurley (1962). The upper, predominantly detrital part, is here called the \( A_1 \), and the lower part, containing less detritus, is called the \( A_2 \). At some localities this unit is red and suggests subaerial deposition or weathering. Detrital units B, C, and D are successively thinner. All detrital units contain more sand toward central Wyoming. Unit D is universally sandy at the top, and thickens toward central Wyoming where the entire interval between D and E is detrital material. Unit E is argillaceous or silty dolomite, and unit F is mainly a brecciated unit with minor detritus. Detrital units G and H are sandy intervals generally found in Wyoming where unit I locally forms a basal detrital unit.

Evaporite-solution breccias and algal stromatolites are associated with the detrital units at many localities. These features all indicate shallow restricted water and/or subaerial conditions of deposition and can be used interchangeably in intraformational correlation.

Detrital unit D occurs about in the middle of the Lower Member (Fig. 11) and separates the limestone and dolomite units named by Sloss and Laird (1947). A shale in a similar stratigraphic position was used in northern Montana by Wilson (1955) to separate the upper and lower parts of the Duperow.
Detrital units A, B, D, and D are continuous southward from Logan, Montana (Fig. 11), over the eastern edge of the Tendoy dome into western Wyoming. Lower detrital units are inconspicuous and difficult to correlate in west-central Montana. In southwestern Montana, all detrital beds are difficult to locate because sections are poorly exposed. The Jefferson Formation in the miogeosyncline of Utah, Idaho, and western Montana contains little detritus.

Detrital units increase in number eastward across southern Montana (Fig. 12). The lower detrital units disappear westward by onlap on the Tendoy dome. In the northern Beartooth Mountains detrital units A, E, C, D, and G are widespread, whereas E and F are less prominent.

The detrital units extend continuously from Yellowstone Park to the south end of the Teton Range (Fig. 13). The top part of detrital unit B becomes sandy in the Teton Range. At LaBarge Mountain, in the northern Green River basin, unit B forms a 20-foot thick light gray quartzitic sandstone. A similar thick sand is present in many wells in the Green River basin. The detrital units below D were not consistently recognized south of the Teton Range. Detrital unit I forms the basal 5 to 10-foot sandy dolomite of the Jefferson Formation in the thrust belt south of the Teton Range and locally contains rounded pebbles and carbonaceous material.

The Lower Member of the Jefferson extends eastward from the Teton Range as the Darby Formation, in which detrital units constitute a major part. Sand-size detritus increases eastward (Fig. 9) and may be present in as much as 20 percent of the Darby Formation.
Fig. 9. Percentage of Lower Member containing sand
Additional detrital units that appear eastward are numbered with a subscript as \( C_1, C_2, \) etc. Detrital units \( B, C, \) and the upper part of \( D \) contain much sand. The intervening non-detrital dolomite ledges average about 10 feet in thickness and are used with the detrital units in tracing the Darby Formation laterally into the Lower Member of the Jefferson Formation.

A bed of sandy dolomite less than one foot thick lies uniformly about two feet above the sharp top of the \( D \) detrital unit in nearly every measured section of the Darby Formation and demonstrates the remarkable lateral persistence of rock types.

In the western part of the Owl Creek Mountains, the prominent sandstone near the top of the Darby Formation is detrital unit \( C \). In the eastern Wind River Mountains, units \( B \) and \( C \) are prominent sandy zones. A core described from a well near Rock Springs, Wyoming, contains several sandy zones, probably representing the \( B, C, \) and \( D \) detrital units. The large increase in sand percentage (Fig. 9) near the eastern erosional edge of Devonian rocks suggests that the depositional edge was not much farther east. The cross-bedded sands near the present edge may represent ancient offshore bars or beach and dune deposits.

**Limestone and dolomite distribution.** The upper dolomite and lower limestone units of the Jefferson Formation were named by Sloss and Laird (1947). These names can be applied to the Lower Member of the Jefferson Formation at the Logan, Montana, type section. The upper dolomite unit lies above detrital unit \( D \) and is composed of brownish
gray fine-to medium-crystalline dolomite with thin detrital units at intervals of 30 to 40 feet. The lower limestone unit underlies the D detrital unit and is mostly dark gray very finely crystalline dense limestone with a medial sacchroidal dolomite (Fig. 11). The limestone is typically mottled in its upper part. Hurley (1962) noted that the lower third of the Duperow (Lower Member) in northwestern Montana is sublithographic limestone.

Detrital unit D is the most consistent division between the lower limestone and overlying dolomite. Locally this boundary is crossed by a few feet of one of the carbonate types. The sharp contacts mentioned in other reports are local in occurrence and not laterally persistent, but appear to be near detrital unit D.

Some of the confusion regarding this subdivision stems from unclear differentiation of limestone and dolomite in earlier reports. Observations reported by this writer are mainly the result of field work using abundant amounts of a 10-percent HCl solution.

Limestone makes up more than 30 percent of the nondetrital carbonate rocks of the Lower Member (Fig. 10) in most of west-central Montana. The lower limestone unit can be distinguished in most parts of west-central Montana, but it has not been recognized as a mappable unit at the scale presently used. The lower part of the Jefferson appears to have been dolomitized in structurally deformed areas. In most places south and west of Logan, Montana, the entire Jefferson is dolomite.

Very little of the lower limestone unit is present in southwestern Montana due to depositional onlap over the Tendoy dome. Sloss
Fig. 10. Limestone percentage of non-detrital carbonates in Lower Member
and Moritz (1951, p. 2151) noted that the lower (limestone) member appears to have been deposited only on the lower or more negative portions of the pre-Devonian surface and is represented by only a few to a few tens of feet of dense dolomitic limestone. An anomalously thick limestone in their Cedar Creek section is actually of Cambrian age.

Scholten and Hait (1962) were able to follow light-colored porous limestone southwest through the Beaverhead Range into Idaho. This limestone occurs at a higher stratigraphic level than the lower limestone unit of Sloss and Laird. They also reported a thicker light-colored porous limestone from the upper part of the Jefferson in the northern Lemhi Range.

In the northern Beartooth Mountains, limestone is prevalent throughout the Lower Member of the Jefferson Formation, except between detrital units A and B. Fossils are well preserved, and little dolomitization has taken place.

Limestone and dolomitic limestone are common in the lower half of the Lower Member along the western border of Wyoming south of Yellowstone Park, especially in the Snake River and Salt River Ranges. Here the lower limestone unit averages about 120 feet in thickness and forms a series of dark-gray ledges at the base of the Jefferson Formation. The unit is mottled with dolomite, detritus is scarce, and brachiopods and oncolites are present. This limestone appears to persist eastward as far as the Gros Ventre Range and coincides in stratigraphic position with the lower limestone unit of Sloss and Laird in west-central Montana. Carbonate beds within the Darby Formation in west-central Wyoming are nearly all of dolomitic composition (Fig. 10).
The Lower Member cannot be divided into limestone and dolomite units in all places; where it can be divided, the contact is not everywhere at the same stratigraphic position. The informal use of such units should be limited to beds similar in appearance and stratigraphic position to the limestone and dolomite units of Sloss and Laird, separated by detrital unit D. West-central Montana and western Wyoming appear to be two places where such a subdivision can be recognized. Other localities on the outer edge of the shelf near the transition zone with the miogeosyncline may contain these two distinct units. In other areas the division may be absent or difficult to make. Arbitrary placement of such a boundary detracts from regional stratigraphic interpretation. Because this division cannot be persistently recognized, detrital beds appear to be more reliable, when present, for intraformational correlation.

Fossil beds. Fossils are rare in the Jefferson Formation. Most of those present are dolomitized and identification is difficult. Abundant fossil concentrations can be used for intraformational correlation. These are beds of abundant fossils, not zones of a certain genus or species, and are used for physical correlation, not age equivalence.

Algal stromatolites generally occur near the outer margins of the Devonian shelf where they were preserved from scouring effects. Most occur between the B and D detrital units and are associated with detrital horizons. The laterally-linked hemispheroid (LLH) variety of Logan, Rezak, and Ginsberg (1964) is the dominant form and is as much
as two feet in height and five feet in diameter. Many oncolites are preserved in areas where hemispheroids are lacking.

"Spaghetti" beds are abundant in the Jefferson Formation and have been variously interpreted as representing algal colonies, worm burrows, and poorly preserved corals. These forms are actually dendroid stromatoporoids of the genus Amphipora. The larger stromatoporoids were divided into round and lenticular varieties. Beds containing stromatoporoids and algal stromatolites are useful in correlation.

In west-central Montana various stromatoporoids, algal stromatolites, corals, and a few brachiopods are concentrated just below detrital unit C (Fig. 11). A lower fossiliferous bed in the middle of the lower limestone unit contains mainly stromatoporoids.

The upper fossil bed (near detrital unit C) is present throughout southwestern Montana. In the Beartooth Mountains, abundant brachiopods and oncolites occur in the middle part of the Lower Member of the Jefferson Formation. In western Wyoming, brachiopods, stromatoporoids, and oncolites are abundant near the top of the lower limestone unit.

In west-central Wyoming, the basal Derby carbonate beds contain a variety of corals, stromatoporoids, and a small mat-like alga (?) less than 1/4 inch thick and 1 inch square. This fossil zone can be traced westward to the Teton Range (Fig. 14). The basal fossil occurrence suggests that only the first marine waters invading the area were favorable for organisms and that later waters were possibly too saline. Above this basal occurrence fossils are rare or lacking in carbonate beds of the Derby Formation. Fish remains, plant
fragments, and conodonts are reported from the detrital interbeds. Fish remains are locally abundant in channel fills at the base of the Darby Formation.

Regional Distribution

The cross sections shown in Figures 11-16 illustrate the correlation of strata within the Lower Member of the Jefferson Formation. The lithological legend of Table 2 explains the symbols used in the cross sections. The base of the Birdbear Member is used as a datum plane. The fence diagram (Fig. 7) shows the regional distribution of the Lower Member and Birdbear Member.

West-central Montana. Figure 11 demonstrates lithologic correlations southward from the type section at Logan, Montana. Strata thin toward the Wyoming shelf and, the lower limestone unit, named by Sloss and Laird (1947) at Logan, thins southward due to onlap and eventually disappears. Detrital units A, B, C, and D and fossil beds just below C, D, and E (?) detrital units are useful in intraformational correlation. Many detailed correlations can be made using other detrital beds, stromatolitic horizons, Amphipora beds, and breccias. A few correlations are shown.

Southern Montana-northern Wyoming. Figure 12 illustrates correlation within the Lower Member along the Montana-Wyoming border. The Lower Member thickens somewhat east of Yellowstone Park, and carbonate beds become more calcareous. Intraformational correlation is based mainly on carbonate ledge-forming units and detrital interbeds. Breccias are prominent at Clarks Fork Canyon and may be partly of
**Table 2**

Lithologic symbols

- **W** WORM
- **◊** FISH
- **▽** BRACHIOPOD
- **☆** CRINOID
- **A** AMPHIPORA
- **S** ROUND STROMATOPOROID
- **S** LENTICULAR STROMATOPOROID
- **♀** CORAL
- **♀ th** THAMNOPORA
- **♀** MATLIKE ALGA
- **♀** ALGAL STROMATOLITE
- **♀** ONCOLITE
- **♀** GASTROPOD

- .0156 mm, very finely crystalline & microcrystalline
- .0156 mm, finely or medium crystalline
- SANDSTONE
- ANHYDRITE
- SILTSTONE
- CHERT
- HEMATITE
- PYRITE
- MUDSTONE
- SHALE
- LAMINATION
- VUG
- CARBONACEOUS SHALE
- COVERED
- RIPPLEMARK
- PARTIALLY COVERED
- BRECCIA
Fig. 11. Lower Member of Jefferson Formation in southwestern Montana
Fig. 12. Lower Member of Jefferson Formation, southern Montana-northern Wyoming
tectonic origin, although Sandberg (personal communication, 1963) has found evidence of reworking by water. Latest Devonian erosion removed the Three Forks Formation, Birdbear Member, and about 100 feet of the Lower Member at Shoshone Canyon near Cody, Wyoming. The Lower Member of the Jefferson Formation constitutes the entire Devonian section in the southern Bighorn basin.

Along the northern edge of the Beartooth Mountains, sections measured at Livingston Canyon, Mission Canyon, and Baker Mountain are mainly limestone in their carbonate portion. Thickness and intra-formational correlations are consistent with sections along the Wyoming border.

**Southwestern Montana and east-central Idaho.** The main feature in this area is the Tendoy dome (Fig. 7), a Late Devonian topographic high over which the Jefferson rocks onlap and disappear near the crest. This high was first named the Lemhi arch by Sloss (1954) on the basis of rapid eastward thinning of the Jefferson Formation. It was later named the Tendoy dome by Scholten (1957, p. 167) for the positive area in the southern Tendoy Range and surrounding area. Scholten and Hait (1962) show evidence that the entire Jefferson may be missing locally near the center of the dome and that thinning of the Jefferson occurs in the adjacent area. The Three Forks Formation was the first unit to extend completely across the dome, which existed as an offshore island during Jefferson deposition. According to Scholten (1960), the uplift may have involved active fault blocks as well as regional warping. The thinnest Jefferson section measured by the writer was near Sunset Peak in the Snowcrest Range, where only a few feet of the
Lower Member is present. Further west the Lower Member thickens off the northwest side of the dome (Fig. 8), but the lower limestone unit is missing on the dome and westward.

**Western Wyoming.** Figure 13 illustrates the intraformational correlation within the Lower Member of the Jefferson Formation from Yellowstone Park to the Green River basin. Lateral persistence of individual units is well shown by sections at Teton Creek and Taylor Mountain located about 12 miles apart in the Teton Range. The Lower Member and Birdbear Member are distinctive well-exposed units throughout the Teton Range.

The total Jefferson thickness increases abruptly by 100 feet south of the Teton Range (Fig. 8) in the thrust belt. The Lower Member averages 280 feet in the thrust belt as compared to 240 feet in the Teton Range and further north. Individual beds within the Lower Member are thicker in sections exposed in the Snake River and Salt River Ranges which were originally farther west before thrust faulting. A distinct limestone unit forms the lower 120 feet of the Jefferson Formation in the thrust belt area. Portions of the Jefferson Formation are repeated by faulting in western Wyoming resulting in apparent variance of thickness in previous reports.

The Lower Member is correlated eastward from the Teton Range in Figure 14 into the Owl Creek Mountains where it forms the Darby Formation.

Figure 15 illustrates correlation of the Lower Member from the southern Teton Range across the Gros Ventre Range to Sheep Mountain, the type section of the Darby Formation in the Wind River Mountains.
Fig. 13. Lower Member of Jefferson Formation in western Wyoming.
Fig. 14. Devonian System from Teton Range to Owl Creek Mountains
Fig. 15. Devonian System from Teton Range to Wind River Mountains
Green River Basin. The Devonian rocks exposed at LaBarge Mountain in the north-central part of the Green River basin are partially faulted, but a complete section was measured which correlates well with Jefferson rocks farther north along depositional strike. Gamma-ray-neutron and lithologic logs from wells in the Green River basin show lithologic units similar to the LaBarge Mountain section. The detritus-bearing Lower Member forms a distinctive unit between the relatively pure dolomites above and below (Fig. 16). The appearance of round frosted sand grains characterizes the Lower Member. Well samples are difficult to use for intraformational correlation due to rapidly alternating carbonate and detrital units. Some of the wells contain more than one Devonian section because of thrust faulting; the upper one is generally thickest. Samples were examined and dipmeter surveys checked for some of the wells.

The Jefferson Formation in The California Company Deadline Ridge Well No. 1 northwest of LaBarge Mountain (Fig. 2) correlates closely with the outcrop sections. Carbonate and detrital interbeds from 1910 to 2195 feet depth comprise the Lower Member. A thick sandstone near the top corresponds to detrital unit B. Detrital unit A is marked by brownish red shale.

In the Mobil Tiptop Well No. 22-19, directly north of LaBarge Mountain (Fig. 2), the Lower Member from 14,690 to 14,920 feet depth is slightly thinner than in the outcrop and appears to be in a lower thrust plate.

In the Carter Meridian Ridge Well No. 1 west of LaBarge Mountain (Fig. 16), the Lower Member of the Jefferson Formation was
System from Green River basin to northeastern Utah.
encountered below 7600 feet and below 11,300 feet depth. The member is about 100 feet thicker in both intervals than at LaBarge Mountain. Detrital units are most conspicuous at the top of the Lower Member (detrital unit A) and about 50 feet below the top (detrital unit B). Sand is present mainly in the upper part of the Lower Member.

The Lower Member in the Max Pray Government Barbari Well No. 1 just south of LaBarge Mountain (Fig. 2) occurs between 4025 and 4245 feet depth. A loss of 45 feet from the section appears to be due to southward onlap over the Utah arch.

In the Belco Petroleum Hamsfork Well No. 30-2, 50 miles south of LaBarge Mountain and south of Kemmerer, Wyoming, the Lower Member can be recognized below 8935 feet depth but is faulted at the base. Sandstone representing detrital unit B is present, and anhydrite flakes were identified by the American Stratigraphic Company.

The Jefferson Formation in the Amerada Fossil Well No. 1 (Fig. 16) differs from others in the Green River basin. Only a 180-foot section below 1350 feet appears similar to the Lower Member of the Jefferson Formation. Nearly half of this interval is sandstone; thick sandstone 60 feet below the Birdbear corresponds to detrital unit B. This thin highly detrital Lower Member corresponds to the upper two-thirds of the Lower Member at LaBarge Mountain and probably represents depositional onlap of the Jefferson Formation over a portion of the Utah arch. Thrust faulting later moved these nearshore rocks eastward closer to thicker Jefferson sections.

On the Rock Springs uplift, Mountain Fuel's U.P.R.R. Well No. 4 cored at least 125 feet of Devonian rocks equivalent to the Lower
Member. The overlying Birdbear Member and Three Forks Formation are missing. These rocks can be referred to the Darby Formation.

Two factors affect the distribution of the Jefferson Formation in the southern Green River basin. A Late Devonian topographic high called the Utah arch existed near the present-day Uinta arch. The Jefferson lapped over this arch during deposition and disappeared southward. This onlap is shown in the Amerada Fossil well west of Kemmerer. Similar southward onlap can be demonstrated in outcrops in northeastern Utah. The southern edge of the Jefferson Formation is shown in Figures 7 and 8.

Latest Devonian erosion cut into the Jefferson Formation from the east. The Birdbear and overlying rocks and the upper part of the Lower Member have been removed from the Devonian section in the Mountain Fuel U.P.R.R. well in the Rock Springs uplift. The western effect of this erosion extends to somewhere between Rock Springs and Kemmerer. The eastern zero edge of Devonian rocks lies within the Green River basin, not far east of Rock Springs, and is due to combined effects of onlap and later erosion.

**Darby Formation**

Original definition. Blackwelder (1918) first applied the name Darby Formation to Devonian rocks in western Wyoming. The name was "derived" from the canyon of Darby Creek on the western side of the Teton Range; but the "typical" section described by Blackwelder is exposed on the eastern slope of Sheep Mountain in the northern part of the Wind River Mountains, some 60 miles to the southeast. Devonian
rocks exposed in the "typical" Darby section at Sheep Mountain are not stratigraphically equivalent to the entire Devonian section in the Teton Range. At this latter locality the Jefferson Formation, including the Lower and Birdbear Members, and the Three Forks Formation are recognized and have been traced southward from their type section in Montana. At Sheep Mountain, the Three Forks and nearly all of the Birdbear are missing because of pre-Madison erosion.

Use of term. The term Darby Formation has long been used in west-central Wyoming to apply to a thin mappable rock unit, containing detrital beds, between the Ordovician Bighorn Dolomite and the Mississippian Madison Limestone. Regional unconformities separate the Darby from both these formations.

The Darby Formation in the northern part of the Wind River Mountains was mapped by Richmond (1945), Baker (1946), Keefer (1957), and Reeves (1958). Love (1939) differentiated the Darby Formation in the southern Absaroka Range, and Masursky (1952) in the western part of the Owl Creek Mountains. Numerous reports on the geology along the east flank of the Wind River Mountains include mention of the Darby Formation. Thomas (1948) and Strickland (1957) correlated sections of the Darby Formation between the Wind River and Owl Creek Mountains. The term Darby Formation has also been used along the eastern edge of the Absaroka Range and in the subsurface of the Wind River basin.

The term Darby has not been used extensively outside west-central Wyoming. To the west and northwest the Devonian rocks are not stratigraphically equivalent to the type Darby and can be divided into the Jefferson and Three Forks Formations.
Lithologic correlation. Correlation of the Darby Formation with the Lower Member of the Jefferson Formation is based on tracing of carbonate ledges and detrital interbeds. As shown in Figure 12, the Darby Formation at Shoshone Canyon in the eastern part of the Absaroka Range can be correlated in detail with the Lower Member of the Jefferson Formation in the Beartooth Mountains. Individual units of the Lower Member persist along the southern edge of the Absaroka Range (Fig. 14) eastward as the Darby Formation in the Owl Creek Mountains. The Lower Member of the Jefferson in the Teton and Gros Ventre Ranges (Fig. 15) continues eastward into the type Darby section at Sheep Mountain in the Wind River Mountains, where the overlying Birdbear and Three Forks are absent.

Restriction of term Darby. East of the erosional edge of the Birdbear and Three Forks, the Lower Member of the Jefferson Formation persists as a mappable unit called the Darby Formation. This use agrees with Blackwelder's original definition and with subsequent popular usage in west-central Wyoming. The Darby Formation is here restricted to the Wind River Mountains, Owl Creek Mountains, southeastern Absaroka Range, and associated basins.

The western limit of the Darby Formation is the Three Forks-Birdbear erosional edge. Detailed control in the southern Absaroka Range (Fig. 14) shows the Three Forks and Birdbear completely removed within a lateral distance of 7 miles. The regional trend of this erosional edge is shown in Figure 7. The eastern edge of the Darby Formation is the eastern edge of Devonian rocks.
Different usage. Unfortunately the term Darby has been applied by some geologists to the entire Devonian section of western Wyoming and eastern Idaho. In these more westerly areas, however, the two members of the Jefferson Formation and the Three Forks Formation can be recognized.

Blackwelder tentatively correlated the Darby with the Jefferson and Three Forks Formations. The term Darby was applied to all Devonian rocks in western Wyoming by Andrichuk (1956), who divided it into Jefferson and Three Forks equivalents, but misplaced all the Devonian rocks in the Wind River Mountains in the Three Forks. Wanless et al. (1955) also called Devonian rocks in western Wyoming the Darby Formation, although these authors distinguished a thick dolomite (Birdbear Member) at the top of the Jefferson, and an overlying Three Forks equivalent which was truncated eastward beneath a regional unconformity.

Having found Devonian rocks poorly exposed at Darby Canyon in the Teton Range, Reeves (1964) proposed a type section for the Darby on the south wall of Teton Canyon, a few miles to the north. He measured about 200 feet of Devonian rocks (Lower Member of Jefferson) at Teton Creek, but mistakenly placed 16.5 feet of overlying shale (detrital unit A) in the Devonian-Mississippian Englewood Formation. Above this shale at both Teton Creek and Darby Canyon is 60 feet of massive dolomite belonging to the Birdbear Member of the Jefferson, which Reeves apparently mistook for the Madison. Overlying the Birdbear is the Three Forks Formation and a thin dark shale unit. Figure 11
Fig. 17. Devonian rocks at Darby Canyon
illustrates the Birdbear, Three Forks, and dark shale unit at Wind Cave on the south side of Darby Canyon.

The term Darby Formation has recently been used for rocks in western Wyoming and eastern Idaho by geologists needing a single name for the entire Devonian interval, in the belief that Devonian rocks in the Teton Range are typical of the Darby Formation. A single name may be needed for mapping purposes, but the term Darby is in use for the Lower Member of the Jefferson Formation where overlying Devonian rocks are absent in a restricted area of west-central Wyoming.

**Description.** The Darby Formation consists of dark fine- to medium-crystalline thick-bedded dolomite ledges separated by less resistant beds of shale, mudstone, siltstone, sandstone, detrital carbonates, and very finely crystalline light-colored carbonates. The detrital interbeds are thicker and more numerous than in equivalent strata to the west and northwest. Sand content in the detrital beds increases toward the southeast. The Darby Formation disconformably overlies the Ordovician Bighorn Dolomite, and in places the Lower Devonian Beartooth Butte Formation; it is overlain unconformably by the dark shale unit of Devonian and Mississippian age. The dark shale overlies various formations above a regional unconformity and is associated with deposition of the overlying Madison Limestone. For stratigraphic purposes, the dark shale unit should not be included in the Darby Formation, although it is locally mapped with the Darby in the generally covered interval between the Bighorn and Madison units. The dark shale unit thins eastward and becomes dolomitic. Where it disappears, the Darby Formation is directly overlain by the Madison Limestone.
Four prominent subdivisions of the Darby can be differentiated in Figures 12, 14 and 15. Darby unit 1 at the top of the formation includes detrital units A, B, and C and the intervening dolomite ledges. The contact with the overlying dark shale unit is placed below the lowest carbonaceous shale and above the highest zone of round frosted sand grains. This uppermost unit thins eastward due to pre-Madison erosion. The two thick sandstones near the base are the B and C detrital units.

Darby unit 2 includes three or more thick resistant dolomite ledges separated by thin detrital units. Darby unit 3 includes the lower less resistant part of the Darby Formation, mostly of detrital beds with thin dolomite strata, below the sandstone of detrital unit D. Darby unit 4 at the base of the formation includes thick-bedded dolomite and detrital interbeds below detrital unit F. Local pebbly and carbonaceous channel fills, possibly equivalent to the Maywood Formation, occur at the base of this unit.

Reference section. The type section of the Darby Formation at Sheep Mountain in the northern part of the Wind River Mountains has been summarized by Richmond (1945) and Baker (1946). It is difficult to reach and has not been described in detail. A reference section supplementing the type section was established and described by Benson, Murphy, and Sandberg (in preparation) at Warm Spring Canyon, approximately 20 miles north of Sheep Mountain. The reference section has also been described by Andrichuk (1956), Keefer (1957), Strickland (1957), and Reeves (1958). Detailed correlation of the type and reference sections is shown in Figure 15.
Distribution. The general distribution of the Darby Formation is shown in Figure 7 and its thickness in the isopach map of the Jefferson Formation (Fig. 8). The Derby Formation thins eastward due to thinning of individual units (especially the carbonates), transgressive onlap over older rocks, and progressive removal by pre-Madison erosion. The eastern edge of the Darby Formation, shown on the diagrams, has been noted in part by Strickland (1957) and Sandberg (1961a).

Discussion. The type section of the Darby Formation described by Blackwelder on Sheep Mountain contained 38½ feet of dolomite, shale, and minor sandstone. Comparison with the section measured by this writer in Benson, Murphy, and Sandberg (in preparation) shows that Blackwelder's Unit 25, an 80-foot dolomite at the top of the section, belongs in the Madison Limestone; and units 23 and 24 comprise the dark shale unit. A 5-foot erosional remnant of the Birdbear is present at the top of the Darby Formation immediately below the dark shale unit. The total thickness of the Darby type section as thus redefined is 262 feet.

The reference section at Warm Spring Canyon west of Dubois, Wyoming, is easily reached from the main highway and is best exposed near the cliff top on the north side of the canyon. Some relief is present at the base, and Keefer (1957) mentions a possible sinkhole deposit in the top of the Bighorn Dolomite. The overlying dark shale unit (Fig. 15) begins with the lowest thick carbonaceous shale or silty dolomite with crinoids, worm impressions, and Tachnurus "swash" marks.
Devonian stratigraphic relations along the southern margin of
the Absaroka Range are shown in Figure 15. The Derby Formation near
Brooks Lake correlates almost perfectly with the type Darby at Sheep
Mountain southward along the depositional strike. A well-exposed
section along the East Fork of DuNoir River contains a 27-foot con-
glomeratic channel fill at the base which is not present to the west
or east, but is stratigraphically equivalent to basal beds at Sheep
Mountain to the south. The lower half of the Darby in the western part
of the Owl Creek Mountains is light brownish gray dolomite. Near the
top is a white cross-beded sandstone of detrital unit C. The Derby
Formation thins eastward in the Owl Creek Mountains from a maximum of
125 feet to the eastern zero edge which was noted by Strickland (1957)
in Wind River Canyon eight miles south of Thermopolis.

Along the east flank of the Wind River Mountains, the Darby
Formation is well exposed at Jackeys Fork (Fig. 15) where an island
existed during earliest Darby deposition. Initial Darby deposition
began on the north, west, and south sides of this low topographic
feature. Sections measured by W. F. Bailey (written communication, 1963)
and Strickland (1957) to the southeast at Dinwoody Canyon and Bull Lake
Canyon total about 200 feet in thickness. The southeastward thinning
of the Darby from Bull Lake Canyon was illustrated by Strickland
(1957, Fig. 4). At Washakie Reservoir only 95 feet of Darby remains
and farther southeast at Trout Creek this writer found only 32 feet.

Along the north wall of the North Fork of Popo Agie River, Bailey
(written communication, 1963) measured a series of sections in which
20 feet of sandstone with thin partings of greenish shale and sandy
dolomite disappear eastward within one-half mile. In Sinks Canyon of the Middle Fork of Popo Agie River, a maximum of 10 feet of highly cross-bedded sandstone and dolomite lies between the Bighorn Dolomite and Madison Limestone. This is the southeastern-most Devonian outcrop found by the writer. The eastern edge of Devonian rocks (fig. 8) continues southward in the subsurface toward the eastern side of the Rock Springs uplift.

On the western side of the Wind River Mountains, the Darby Formation was found only at Steele Butte. The lower third is brownish fetid crystalline dolomite and is overlain by a distinctive greenish gray mudstone. White quartzitic sandstone of detrital unit C and silty sandy dolomite of detrital unit B occur near the top.

The Darby Formation was cored in the Mountain Fuel U.P.R.R. Well No. 4 about 10 miles north of Rock Springs, Wyoming. This significant section is similar to outcrops of the Darby Formation; dolomite, sandstone, and shale are the dominant rock types. Although correlations are tentative, the thicker sandy units appear to represent the B₁, B₂, C, C₁, C₂, and D detrital units. Sandstone is abundant because of nearness of the Late Devonian shoreline. The lower portion of the Darby appears to have disappeared by onlap. The presence of the Darby Formation in this well indicates that Devonian rocks, although at great depths, are present throughout most of the Green River basin.
Birdbear Member

Definition and Previous Work

The name Birdbear was proposed by Sandberg and Hammond (1958, p. 2318) for the upper formation of the subsurface Jefferson Group in the Williston basin. The type subsurface Birdbear comprises the interval between 10,310 and 10,400 feet in the Mobil Producing Company's Birdbear Well No. 1 in western North Dakota. The Birdbear in outcrop forms the upper 70 feet of the type Jefferson Formation near Logan, Montana, and was described by Sandberg (1962). Subsurface correlation by Sandberg and Hammond and by Sandberg (1961a), stratigraphic relations, and lithology leave little doubt that the subsurface Birdbear Formation in the Williston basin and the outcropping Birdbear Member in western Montana are the same lithic unit.

Description. The Birdbear Member of the Jefferson Formation is composed of light brownish-gray finely crystalline dolomite. It is nodular, vuggy, slightly fetid, very thick-bedded, sometimes faintly brecciated, and usually weathers to a somewhat lighter color. The basal 2 to 6 feet is locally calcareous, dense, and faintly bedded, and forms a reentrant at the base of the imposing Birdbear cliff.

The upper portion of the Birdbear in the subsurface contains some anhydrite. The upper several feet of the Birdbear is locally lighter in color and coarsely crystalline. In northeastern Montana, the Birdbear is divided by Blair (1962) into a
dolomitized lower unit containing stromatoporoid biothermal growths with intra-reef deposits and basinal limestone. The upper half is dolomitized algal limestone and anhydrite. In the Nisku (Birdbear equivalent) of central Alberta, Thomas (1962) found an algal-stromatoporoid, coralline organic barrier separating typical Nisku rocks from open marine limestone and shale to the northwest. The restricted facies to the southeast consists of organic and clastic carbonate shoals in areas of the underlying Leduc reefs. Lagoonal areas contain evaporites and brown pelletal carbonate muds containing amphiporoids. The upper Nisku consists of a regressive anhydrite.

The Birdbear in outcrop typically forms a resistant ledge (Fig. 18). At the Jefferson type section near Logan, the beds are moderately dipping and the Birdbear is partially covered.

The contact with the underlying Lower Member is conformable, although locally there may be a few inches of relief on top of the widespread shale of detrital unit A. The contact with the overlying Three Forks Formation is generally even and sharp. Local thinning of the Birdbear, basal clastic beds in the Three Forks, and evidence of local erosion at the contact (Sandberg, 1965) suggest a minor hiatus following Jefferson deposition.

Distribution

The Birdbear is an easily recognized, widespread unit extending from the eastern Dakotas to western Montana and southward into northern Utah. The lateral persistence, thick uniform lithology, and cliff-forming nature of the Birdbear Member characterize the upper part of
Fig. 18. Birdbear Member at Taylor Mountain, Teton Range
the Jefferson Formation throughout the shelf area. In the miogeosyncline it is difficult to distinguish the Birdbear from thick underlying carbonates in the Jefferson.

The eastern edge of the Birdbear Member (Figs. 7 and 8) established by pre-Madison erosion passes along the west side of the Bighorn basin in northern Wyoming, swings southwest toward the western Wind River Mountains, and extends directly southward between the towns of Kemmerer and Green River, Wyoming. The Birdbear is confined to north of the Uinta arch. This latest Devonian-Early Mississippian erosion locally removed the Birdbear and overlying Three Forks within a few miles, forming an escarpment that was later covered by carbonaceous muds of the Devonian-Mississippian dark shale unit (Fig. 19). Its persistent lithology and thickness up to this eastern erosional edge indicate that the Birdbear probably extended farther eastward before the pre-Madison erosion.

The distribution and thickness of the Birdbear Member in the Late Devonian shelf area are shown in Figure 20. The eastern erosional edge in Montana was defined by Sandberg (1961a). The Birdbear ranges in thickness from a feather edge to 128 feet in northeastern Utah; it averages 60 to 115 feet. Sandberg and Hammond (1958) found that the Birdbear in the Williston basin maintains a thickness between 75 and 115 feet. In west-central Montana and southward to the Teton Range in Wyoming, the Birdbear thickness is consistently about 60 feet but there is a gentle increase westward to 115 feet.

The Birdbear thins and apparently disappears locally in southwestern Montana by onlap on the Tendoy dome. Scholten and Hait
Fig. 19. Schematic cross section of Devonian stratigraphic relations in west-central Wyoming.
(1962, Fig. 2) found one section (Little Sheep Creek in the Tondoy Range) near the crest of the arch where no Jefferson is present. In the southern part of the Madison and Gravelly Ranges and in southwest Montana, the Birdbear is consistently less than 50 feet thick; just west of Yellowstone Park it is only 33 feet thick. The Birdbear may also be abnormally thin beneath the volcanics of Yellowstone Park. Only 27 feet appears at Clarks Fork Canyon in the eastern Beartooth Mountains, and even less is present in the western Bighorn basin. This may be the result of depositional thinning or the effects of local pre-Three Forks erosion.

The Birdbear is distinctive and easily recognized in the Green River basin, especially on gamma ray-neutron logs, due to underlying and overlying detrital beds. Anhydrite flakes are present locally.

**Jefferson Formation Undifferentiated**

**Introduction**

The miogeosynclinal facies of the Jefferson Formation in western Montana, eastern Idaho, and northern Utah can be readily distinguished from the overlying Three Forks and equivalent formations, but it is difficult to separate the Lower and Birdbear Members. The great thickness of the Jefferson, its uniform lithology and lack of detrital intervals, and the nearly complete dolomitization make intraformational correlation difficult.

The Jefferson rocks in the miogeosyncline are typically dark gray fetid finely crystalline thick-bedded dolomite. Limestone is locally present in western Montana, particularly in the lower half.
Detrital and light-colored interbeds are rare. The dolomite beds are essentially similar except for subtle changes in color and the presence of laminations. Beds containing Amphipora and other stromatoporoids, corals, and algal stromatolites locally form distinctive units. In general, fossils are more abundant than in the shelf area to the east. A north-south cross section from Montana to Utah is shown in Figure 21. Regional distribution and thickness of the Jefferson Formation in the miogeosyncline is shown in Figure 8.

Western Montana

Several Jefferson sections west of Three Forks were measured and described by McMannia (1962) and Robinson (1963). In these sections the Birdbear Member is not so prominent as it is farther east and the total thickness ranges from 400 to 650 feet. The lower part of the Jefferson in these sections is dominantly limestone and contains abundant stromatoporoids, Amphipora, corals (including Thamnopora) and some brachiopods. One hundred or more feet of the Meywood Formation gradationally underlies the Jefferson in this area.

Along Boulder Creek (Fig. 21) northeast of Philipsburg, 980 feet of the Jefferson Formation includes 500 feet of mostly dark gray dense limestone in the lower half and 480 feet of dark gray to black sacchroidal dolomite in the upper half. Corals and Amphipora are abundant at the top above the breccia unit. A black shale above the Jefferson is reported locally in the Philipsburg area and was deposited following an erosional interval during which the Three Forks and possibly some of the Jefferson rocks were removed.
Fig. 21. Devonian System from Montana to northern Utah
Along the East Fork of Rock Creek (Fig. 21) southwest of Philipsburg, 989 feet of the Jefferson Formation includes 500 feet of mostly dark gray dense limestone in the lower part. In the upper half are 489 feet of mostly dark colored dolomite with some light colored limestone in bands that do not conform rigidly to bedding. Overlying the Jefferson is 180 feet of dark gray calcareous shale which appears to grade upward into thin-bedded Lodgepole limestone containing argillaceous partings.

The westernmost exposure of the Jefferson Formation in Montana, in the Nimrod area northwest of Boulder Creek described by Montgomery (1958), appears to be at least 1500 feet thick. The lower part is dense black limestone and the upper part is brownish-purple saachroidal fetid dolomite with some interbedded argillaceous limestone.

Northwestern Montana

Deiss (1933) named several members within the Jefferson Formation in the mountains of northwest Montanas, but these names have not been retained. Sloss and Laird (1946, 1947) named two Devonian units; unit B equivalent to the lower limestone unit, and unit A equivalent to the upper part of the Jefferson Formation and part of the overlying Three Forks Formation. On the Sweetgrass arch, green shale at the top of the Three Forks Formation was thought to be transitional downward into anhydrite which continued with decreasing frequency downward into the Jefferson Formation. Sloss and Laird referred the entire brecciated section to the Potlatch Anhydrite.
Wilson (1955) and Hurley (1962) were able to differentiate the Jefferson from the overlying anhydrite and green shale on the Sweetgrass arch and in the mountains to the west. The Lower Duperow and Upper Duperow correspond to the lower limestone and upper dolomite in west-central Montana. Hurley noted that the Birdbear loses some of its persistent character due to facies changes from carbonate to anhydrite on the arch. The entire Jefferson Formation ranges from 700 to 800 feet thick on the Sweetgrass arch and thickens to more than 1000 feet in the mountains of the thrust belt.

Pre-Madison erosion may have affected the western distribution of the Jefferson Formation. The topmost beds of the Three Forks Formation are present on the Sweetgrass arch but are missing in the mountains to the west. In western Montana the entire Three Forks is missing, and latest Devonian erosion may have removed part of the underlying Jefferson.

East-central Idaho

Work on the Devonian System in east-central Idaho was done mainly by Ross (1934, 1937, 1947, 1961) who referred a lower dark dolomite to the Jefferson Dolomite and overlying lighter dolomite to the Grand View Dolomite. Both of these units lie below the Three Forks Formation and are equivalent to the Jefferson Formation farther east. The Grand View Dolomite proposed by Ross (1934, p. 963) contains 1200 feet of medium crystalline medium gray dolomite which is generally lighter than typical underlying Jefferson dolomite. Minor dark dolomite beds are present and sandy zones are common, but few fossils
are present. The Grand View Dolomite has been differentiated from the underlying dark dolomite only in the northern Lost River Range near the Grand View type section. It appears to be a light-colored miogeosynclinal facies within the Jefferson. Elsewhere in the miogeosyncline, most of the Jefferson is dark dolomite with sandy beds in the upper half. The continuously light-colored dolomite is confined to 140 feet near the base of the Grand View Dolomite. This corresponds in stratigraphic position to the unnamed light-colored dolomite within the Jefferson Formation in southeastern Idaho (Fig. 21). The dark dolomites below the Grand View are highly fossiliferous near the base where the lowest beds may be Middle Devonian according to recent work by Beus (1965).

The Jefferson rests on a regional unconformity and overlies much older rocks near to the Tendoy dome. The Jefferson was eroded from central Idaho prior to deposition of the Milligen Formation. This western erosional edge may extend northward along the Idaho-Montana border. Latest Devonian uplift in the eugeosyncline may represent a northern continuation of the Antler orogenic belt from Nevada. A thick wedge of coarse detritus forming the Milligen Formation was spread eastward from this uplift.

Southeastern Idaho and Northeastern Utah

Rocks typical of the Jefferson Formation extend southward into Utah before overlapping a Devonian arch which extended westward from the present-day Uinta arch. The Jefferson Formation in this area can be correlated with well-known and typical Jefferson carbonates on the
shelf in western Wyoming (Fig. 16). Recent mapping in northern Utah has unfortunately led to the use of Jefferson for the entire Upper Devonian interval (Williams, 1948, 1958; Mullens and Izett, 1964).

The term Hyrum Dolomite was established by Williams (1948) for exposures in Blacksmith Fork Canyon in the Wasatch Range east of the town of Hyrum, Utah. The unit consists predominantly of black dolomite and was placed in the lower part of the Jefferson Formation. The rocks of the Hyrum Dolomite are very similar to rocks characteristic of the Jefferson Formation (Fig. 16) on the Wyoming shelf to the east as well as rocks in the Jefferson throughout eastern Idaho and western Montana (Fig. 21).

The Jefferson Formation at Laketown Canyon, Utah (Fig. 16) clearly includes the Lower and Birdbear Members and underlies limestone and mudstone fairly typical of the Three Forks Formation. Other nearby sections in extreme northeastern Utah in which thick Jefferson and Three Forks Formations occur have been described by Richardson (1913, 1941), Brooks and Andrichuk (1953), and Andrichuk (1956). The dark fetid dolomite in the lower half of the Blacksmith Fork section correlates well with the Jefferson Formation at Laketown Canyon in both rock types and stratigraphic position. Overlying the dark dolomites at both localities are rocks typical of the Three Forks Formation.

The Jefferson Formation as originally defined in Montana forms only the lower part of the Devonian section at Blacksmith Fork. It is recommended that Hyrum Dolomite be abandoned as an infrequently-used term synonymous with the older easily recognized and more prevalent term Jefferson Formation. The Jefferson Formation at Blacksmith Fork
(Fig. 21) contains 782 feet of dark gray fine- to medium- crystalline sacchroidal fetid dolomite with some sandy intervals in the upper half. *Amphipora* and other stromatoporoids, *Thamnopora*, and brachiopods occur in the lower half and algal stromatolites in the upper half. At the top of the Jefferson is 180 feet of dolomite similar to the Birdbear and it overlies 14 feet of argillaceous and quartzose dolomite and mudstone similar to detrital unit A at the top of the Lower Member.

The upper boundary of the Jefferson in the miogeosyncline is placed at the change to light-colored rocks which coincides approximately with the introduction of abundant detritus. This overlying unit, the Beirdneau Formation, is composed of brownish gray to light gray dense very finely crystalline thin-bedded quartzose dolomite.

The Jefferson Formation thickens northward to 1558 feet in the Fish Creek Range near Bancroft, Idaho (Fig. 21). Here the lower 500 feet is medium and dark gray sacchroidal dolomite with abundant brachiopods, gastropods, and crinoids in the upper 60 feet. Southwest along the Utah-Idaho border a similar fossiliferous unit was found by Beus (1965) from 300 to 600 feet above the base of the Jefferson. He suggested that the Middle-Upper Devonian boundary lies in the lower part of this unit. A fossiliferous unit also occurs near the base of the Jefferson Formation at Grand View Canyon in central Idaho.

In the Fish Creek Range a distinctive 250-foot dense very light gray dolomite overlies the fossiliferous unit. This light-colored dolomite is also present in the Soda Springs Hills to the east (Fig. 7) and correlates with the light-colored dolomite at the base of the Grand View Dolomite in central Idaho.
The Jefferson thickens westward at the rate of 80 feet per mile in the Soda Springs area (disregarding tectonic shortening) as compared to less than 5 feet per mile from Bedford, Wyoming, to the Soda Springs Hills. The Jefferson Formation in southeastern Idaho and northeastern Utah lies west of a tectonic hinge line from somewhat similar strata on the Wyoming shelf. The Bannock thrust zone (Fig. 22) extends along the east front of the Wasatch and Bear River Ranges from northern Utah to the Blackfoot Reservoir in southeastern Idaho and facilitates definition of the tectonic hinge in Late Devonian time.

A Late Devonian arch separated the miogeosyncline in northern Utah from the central Utah depositional basin. This broad uplifted area, here called the Utah arch (Fig. 22) was the western part of the Transcontinental arch. Deposition was simultaneous in the two basins which had a marine connection around the arch in western Utah. Complete marine transgression over the arch did not occur until near the end of Devonian time. Partially isolated uplifts, such as in the Stansbury Mountains (Fig. 22), developed on this broad arch according to Rigby (1959).

The Jefferson Formation thins southward onto this arch and pinches out south of the Willard thrust zone near Morgan, Utah (Fig. 22). At Camp Kiesel Canyon, between Blacksmith Fork and Morgan, 435 feet of Jefferson was described by Laraway (1958). At Durst Mountain, south of the Willard thrust zone, Eardley (1944) and Brooks (1959) have reported 600 feet of the Three Forks Formation with no Jefferson present. This suggests southward disappearance of the Jefferson Formation due to onlap over a pre-existing high, the Utah arch.
Fig. 22. Structure and distribution of Devonian rocks in southeastern Idaho and northeastern Utah.
Local uplift and erosion on this arch near the end of Jefferson
deposition has been reported by Morris and Lovering (1961) and Rigby
(1959). This erosion may have reduced the southern extent of the
Jefferson Formation shown in Figure 8 and produced detritus that was
swept northward into the basin during Three Forks-Beirdneau deposition.
Thin sandstone beds in the upper part of the Jefferson Formation in
northeastern Utah may have been derived from earlier small pulses of
uplift and erosion on the arch.

Central and Western Utah

Rocks similar to the Jefferson Formation, but generally
referred to the Simonson Dolomite and the Gilmette Formation, occur
west and south of the Utah arch. West of the area in the southern
Lakeside Mountains, Young (1955) described 703 feet of mostly dark
gray laminated fine- to medium- crystalline dolomite which corresponds
to the Jefferson Formation. In the Promontory Range (Fig. 22) north
of Great Salt Lake the lower two-thirds of the 940-foot Devonian
section described by Olson (1956) is dark dolomite and appears similar
to the Jefferson Formation. Cohenour (1959) correlated 563 feet of
dark gray medium crystalline laminated dolomite with the Jefferson
in the Sheep Rock Range (Fig. 22). Jefferson-type rocks are present
south of the Utah arch in the East Tintic Mountains (Fig. 22). Morris
and Lovering (1961) report the upper member of the Bluebell Formation
(as revised by Morris and Lovering) is probably Late Devonian in age
and predominantly medium dark gray medium crystalline dolomite.
In west-central Utah most of the Simonson Dolomite and overlying Guilmette Formation have a similar appearance and stratigraphic position to the Jefferson Formation. Further correlation is suggested by the work of Osmond (1954), who divided the Simonson into four members, mostly of dark fetid crystalline thick-bedded dolomite with some interbeds of lighter-colored finer crystalline dolomite. The fossils are similar to those found in the Jefferson, but the age of the Simonson based mainly on *Stringocephalus* is Middle Devonian. The Jefferson is generally regarded as early Late Devonian (Frasnian), except for the lowest beds in Idaho and northern Utah.

The Simonson persists into the eugeosyncline in west-central Nevada where Middle Devonian rocks, dated by ostracods and conodonts, are composed mainly of dark shale and chert with some pyroclastics and limestone (Roberts, et al., 1958). Detritus was spread eastward into the basin from the Antler orogenic belt running north-south through central Nevada. Uplift culminated at the end of Devonian time with the Roberts Mountains thrust and may be partly responsible for latest Devonian-Early Mississippian erosion in the northern Rocky Mountains.

The extensive unit of dark fetid dolomite referred to the Jefferson Formation and lithologically equivalent strata is continuous from west-central Nevada across Utah, Wyoming, Montana, and to the eastern Dakotas and far northward into Canada. Although possibly somewhat transgressive in time, these Late Devonian carbonates represent deposition from a widespread epeiric sea covering much of the western and northern United States in Late Devonian time and lapping over the Canadian Shield.
Sedimentation and Origin

The cyclic character of the Jefferson Formation is reflected both in the vertical sequence and in the lateral persistence of individual rock types. Cyclicity is best demonstrated in the Lower Member in Wyoming, which accumulated close to the Late Devonian shoreline. The following sequence is considered typical:

- Siltstone or sandstone
- Shale, silty, greenish, with salt casts
- Carbonate, silty, argillaceous
- Carbonate, dense, very finely crystalline, laminated or brecciated, weathering buff
- Dolomite, dark, fine- to medium- crystalline, fetid, vuggy, with stromatoporoids
- Dolomite, calcareous, dense, thin-beded, with some brachiopods

The dark dolomite forms more than three-quarters of the typical depositional cycle and is ledge-forming in outcrop. The remaining units are thin and form slopes. Farther west and north, where there was less influx of detrital material, evaporites (mainly anhydrite) and evaporite-solution breccias are present in the slope-forming detrital units.

Similar cycles were noted by Wilson (1955) in northern Montana:

- Anhydrite
- Dolomite, brown, sucrosic, vuggy, massive, with stromatoporoids and corals
- Limestone, dolomitized, dense, thin-beded, with brachiopods
- Dolomite, silty, thinly laminated, weathering yellowish-gray

Following marine transgression, the water gradually became shallow and restricted until anhydrite formed. Detritus is present only in the basal phase as a result of distance from shore. The
detritus may have been deposited during regression, but it was
reworked as sea level rose initiating a new cycle. Andrichuk (1951,
p. 2378) noted a similar idealized evaporite cycle for nearshore
deposition in which substantial amounts of detritus are supplied:

- Shale and siltstone
- Silty dolomite
- Dolomite, variegated, shaly
- Dolomite, dense, buff
- Limestone, fossiliferous

Many of these sequences can be followed throughout the Lower
Member of the Jefferson Formation close to the central Wyoming
emergent shelf. Further west and northwest, only the upper half of
the Lower Member exhibits well-developed sequences. The evaporites
are thought to result from deposition in a large back-reef area south
of the Late Devonian Leduc reefs in the Woodbend Formation of central
Alberta. Evaporites do not have to be the result of restricted back-
reef water according to Shaw (1964), who believes that shallow water
may be the only necessary feature.

A cycle starts with fairly rapid marine transgression reworking
any available material into a thin sheet of detritus. Deposition of
the overlying normal marine carbonates comprising most of the depo-
sitional cycle probably required a much longer time. Toward the close
of the cycle, sea level was lowered causing restricted circulation
over wide areas and the formation of evaporitic and detrital rocks.

The thin widespread nature of the silty and sandy detrital units
suggests deposition during lowered sea levels possibly in part by
wave action. Subaerial conditions are suggested by reddish color and
evaporites. "Floating" sand grains may have been deposited by eolian
action in unconsolidated carbonate muds. The detritus was reworked
during subsequent marine transgression. Widespread marine advance and
retreat may have been caused by a change in sea level of only a few
tens of feet. The periodic occurrence of detrital interbeds suggests
such sea-level changes.

Evaporites (mainly anhydrite) are locally associated with the
detrital units in the subsurface. Gloss and Laird (1947, p. 1421-23)
found that anhydrite in the upper Jefferson and Three Forks Formation
is removed by solution in outcrop areas, causing slumping and
brecciation. They named the resulting rocks evaporite-solution breccias.
Similar breccias in the lower Three Forks Group in southern Saskatchewan
were interpreted by Christopher (1962) as regoliths formed by intra-
formational weathering. The red to brown mudstone matrix was thought
to be characteristic of intense and/or prolonged subaerial weathering
and oxidation during oscillatory exposure of the sea floor. Reddish
mudstone has been found associated with slightly brecciated zones in
the Lower Member of the Jefferson, but it is difficult to determine
whether weathering or evaporite solution is the cause.

The thick non-detrital portion of the depositional cycle was
probably precipitated as limestone with a fairly abundant fauna in a
shallow-water normal marine epigeneic sea. Lowering of sea level toward
the end of the depositional cycle restricted circulation and increased
magnesium concentration. Dolomitization by seepage refluxion of these
later waters downward through the underlying lime mud has been
described by Adams and Rhodes (1960). The dolomitizing solutions were
probably early diagenetic rather than contemporaneous with deposition,
and were not necessarily highly concentrated brines. This secondary dolomitization was probably accompanied by penecontemporaneous replacement of surficial carbonate sediments producing the dense light-colored laminated dolomite. Surface concentration of brines led to the formation of gypsum, which was converted to anhydrite upon burial (Murray, 1964). Formation of evaporites protected the underlying carbonates from further dolomitization.

Evaporites and associated nonpermeable shales in the upper half of the Lower Member in west-central Montana and western Wyoming may be partly responsible for retaining the limestone composition in the lower part of the Jefferson. Major detrital units in west-central Montana separate slightly different sequences of rock types.

The upper half of the Lower Member is suggestive of slightly more shallow water because of the restricted fauna of algae, stromatoporoids and corals, and the abundant detrital interbeds and associated evaporites. The lower half of the Lower Member may have formed in slightly deeper water with few cyclic sea level changes because of its relatively varied fauna and lack of detritus and evaporites.

Other features of sedimentation which can be noted on the plates and figures include the relation of basinal subsidence to thickness of units, thinning of individual units toward the eastern shoreline, and the regional distribution of limestone.

Age

The Jefferson Formation is largely dolomitized and few recognizable fossils have been found. Algal stromatolites, stromatoporoids, and corals are the most abundant but are commonly not diagnostic.
The most important early work was by Kindle (1908). He thought the Jefferson was Middle Devonian, on the basis of a few brachiopod species which were characteristic of the Middle Devonian of the eastern United States, and on the absence of other brachiopods common to Lower or Upper Devonian rocks. Fossil identifications from the outcropping Jefferson Formation in Montana, Idaho, Wyoming, and Utah were summarized by Berry (1946).

At Logan, Montana, Berry found the coral *Phillipsastraea* 175 feet above the base of the Jefferson and noted that beds containing this genus mark the base of the Upper Devonian Devils Gate Limestone (Merriam, 1940) in Nevada. Berry found *Spirifer engelmanni* near the base of the Jefferson as did Kindle (1908) at several other localities. In the Nevada Devils Gate Limestone *Spirifer engelmanni* occurs in beds belonging to the *Spirifer argentarius* zone which had been assigned an Upper Devonian age. Thus, Berry assigned the lower part of the Jefferson to the Middle Devonian.

Laird (1947) found the fauna from the lower limestone unit of the Jefferson to be similar to the *Spirifer argentarius* zone in the Devils Gate Limestone. Based on the occurrence of *Spirifer jesperensis* and related forms, this fauna was correlated with Upper Devonian fauna of New York state. Faunal correlations with Canadian equivalents are given by Sloss and Laird (1947). The early Late Devonian (Frasnian or Senecan) age agrees with the age determined for the underlying Maywood Formation (Cooper, 1945; Robinson, 1963).

Nolan, Merriam and Williams (1956, p. 51) noted that *Allanaria engelmanni* is characteristic of the lowest part of the *Spirifer*
argentarius zone in Nevada, but it is stratigraphically below the actual occurrence of *Spirifer argentarius*. They placed the Middle-Upper Devonian boundary below the entire zone (below the strata containing *Allanaria engelmanni*). Middle Devonian rocks are characterized by *Stringocephalus* (Cooper et al., 1942). In the Blue Spring Hills along the Idaho-Utah border, Beus (1965) found *Ambothrys* and *Emanuella* which are common in Middle Devonian rocks. Absence of typical Upper Devonian forms suggests that the lower 300 feet in this area of the miogeosyncline may be Middle Devonian. Stratigraphic correlation shows that these rocks at the base of the Jefferson do not persist eastward onto the shelf. Fossils found by Beus between 300 and 600 feet above the base of the Jefferson suggest correlation with the *Allanaria allani* fauna of the Waterways Formation of Alberta. The *Allanaria allani* fauna occurs above the *Stringocephalus* (definite Middle Devonian) zone and below the *Eleutherokomma leducensis* (definite Late Devonian) zone of Warren and Stelck (1956). A stratigraphic succession of fossil assemblages for the Devonian of western Canada was devised by Warren and Stelck and correlated with the rynchonellid brachiopod zones of McLaren (1954); later revised (1962). The *Allanaria allani* fauna is generally assigned to Late Devonian time. *Allanaria-* *Eleutherokomma* brachiopods are abundant at the top of the Maywood-Souris River unit and lowest Duperow in the Williston basin, central and northern Montana, and northwestern Montana (Wilson, 1955; Hurley, 1962).

The small brachiopod *Rhabdostichus* forms a marker horizon just above the *Allanaria-Eleutherokomma* fauna in the Williston basin (Wilson, 1956). In the middle of the Duperow (Lower Member); Wilson (1955)
noted a widespread coral-stromatoporoid biostratal development at which the lowest *Crytopspirifer* occurs. This appears to coincide closely with detrital unit D in the Lower Member. *Crytopspirifer* marks the beginning of the Onhmuung Series (upper third of the Frasian or Senecan stage).

*Atrypa* is the predominant fossil in the Birdbear according to deWitt and McLaren (1950). A sharp faunal break at the upper limit of Frasian time (Jefferson deposition) includes extinction of *Atrypa*, *Theodossia*, *Hypothyridina*, compound rugose corals, and most stromatoporoids (McLaren, 1962). Fammenian faunas include several new elements, although *Crytopspirifer* predominates.
THREE FORKS FORMATION

Previous Work

The name Three Forks Shale was applied by Peale (1893, p. 29-32) to rocks overlying the Jefferson Dolomite and underlying the Madison Limestone in the vicinity of Three Forks, Montana. The Three Forks was designated as a formation by Haynes (1916) because of the variable rock types. Breccias and associated shales in the lower Three Forks were assigned to the Jefferson Formation by Sloss and Laird (1946, 1947), but these breccias and shales were always found sharply overlying the thick Birdbear dolomite at the top of the Jefferson. The breccias and shales form the lower part of the generally covered Three Forks Formation.

The arenaceous upper part of the Three Forks was named the Sappington Sandstone by Berry (1946, p. 14-16) and was expanded to include underlying carbonaceous shale by Holland (1952). It has often been considered as a separate formation, but its thinness and outcrop nature make it more reasonable to include as a member of the Three Forks Formation.

The type section of the Three Forks was established at Logan, Montana, by Sloss and Laird (1946, 1947) from the outcrop sketch made by Peale (1893). The Sappington type locality is at Milligan Canyon, 12 miles west of Logan. Sandberg (1965) used the Logan locality as a reference section for the Sappington. A detailed description of the type Three Forks section at Logan was given by Sandberg (1962).
Three lithic divisions of the Three Forks Formation were designated by McMannis (1962) and Sandberg (1962); a lower evaporitic member, a middle shale member, and an upper sandstone member. These members have been formally named by Sandberg (1965), in ascending order the Logan Gulch, Trident, and Sappington Members. Distribution of these units is controlled by pre-Madison erosion. The lowest member (Logan Gulch) is the most extensive, and the upper (Sappington) Member is the most restricted.

The Three Forks Formation sharply overlies the Jefferson Formation at all outcrops. The Sappington Member rests disconformably on the underlying Trident Member. A dark shale unit of Mississippian age overlies a regional unconformity and rests on each of the three members at different places.

Logan Gulch and Trident Members

These two associated units sharply overlie the Jefferson Formation and disconformably underlie the Sappington Member of the Three Forks. They are readily distinguished near Logan, Montana, and to the north and west.

The Logan Gulch Member consists mostly of brecciated limestone and shale. The breccias are attributed by Sloss and Laird (1947, p. 1422-23) to evaporite solution. Basal silty and dolomitic shales are also present at Logan. A limestone, which locally serves as a stratigraphic marker, is placed at the top of the Logan Gulch by Sandberg (1965).

In the Logan area and to the north and west, the Trident Member consists mostly of fossiliferous greenish clay shale. Gray dolomitic
limestone and silty dolomite at the base of the member and nodular limestone at the top of the member are included by Sandberg (1965).

To the southeast of Logan, typical solution breccias and green shales are not present in the Three Forks Formation. Brecciated argillaceous dolomite and dolomitic shale are the most common rocks to the southeast where it is difficult to recognize the Logan Gulch and Trident Members. McMannis (1962) included all Three Forks rocks east of typical breccias and green shales in a "carbonate member." Sandberg (1965) was able to distinguish Logan Gulch and Trident equivalents on the appearance of carbonate stratigraphic markers, but these appear to be changeable in character and position. The Trident Member is mostly removed eastward by pre-Madison erosion so the remaining Three Forks rocks are mostly equivalent to the Logan Gulch Member. Because of uncertainties in identifying Logan Gulch and Trident equivalents in the Beartooth Mountains and southward through Wyoming, the two units are discussed together.

**Facies.** Five facies are distinguished within the Logan Gulch-Trident interval. They are informally termed the silty, evaporitic, argillaceous dolomite, green shale, and carbonate facies.

Silty dolomite and dolomitic mudstone constitute nearly the entire Three Forks Formation near its eastern erosional edge in southern Montana and northern Wyoming (Figs. 23, 24). This silty facies also crops out at Targhee Peak, Idaho, suggesting that the facies extends across Yellowstone Park. It may also extend northward in the subsurface of Montana. Much of this facies is reddish in color, although
Fig. 23. Fence diagram of Three Forks Formation
Fig. 24. Lithofacies map of lower third of Three Forks Formation (mostly Logan Gulch Member)
buff mudstone forms the upper part of the Three Forks in the southern Absaroka Range. The source for most of the detritus in the Three Forks was the emergent central Wyoming shelf.

The basal few feet of the Three Forks in the Snake River and Salt River Ranges in western Wyoming contains silt and round frosted sand grains which increase in abundance southward. At LaBarge Mountain in the northern Green River basin, the entire Three Forks interval is silty and sandy. The basal 5 to 10 feet in the southern Absaroka Range also contains round sand grains.

The evaporitic facies varies in stratigraphic position within the Logan Gulch Member. The outcropping rocks are evaporite-solution breccias which are generally argillaceous and have a calcareous matrix. Anhydrite is known from the subsurface of nearby basins. Two large areas of the evaporite facies are known (Fig. 24). In west-central Montana, evaporites have been traced northward by Sandberg (1965) into the upper part of the Potlatch Anhydrite on the Sweetgrass arch. Northwestern Montana was the center of a large evaporite basin that extended into southern Alberta and southwestern Saskatchewan. The eastern edge of the evaporitic facies lies just east of the Bridger Range and continues south to the northwest corner of Yellowstone Park, where only a few feet are recognized. The southern edge of this evaporitic accumulation extends westward (Fig. 24) around the north edge of the Tendoy dome. Isolated lenses of the evaporitic facies may occur near or beyond this zero edge. In the Logan area this facies reaches a thickness of nearly 100 feet.
A second area of evaporitic facies occurs along the Wyoming-Idaho border. A maximum thickness of 40 feet is reached in outcrops in the Snake River Range. East and southeast of this range (Figs. 23, 24) the facies thins gradually owing to removal by pre-Madison erosion. Evaporite-solution breccia forms a distinctive unit in the middle of the Three Forks Formation in the Snake River Range, where it weathers to a bright yellow color. The western edge of the Wyoming-Idaho evaporitic facies is not known, but probably does not extend far into the miogeosyncline. The two major areas of evaporites may be continuous around the west side of the Tendoy dome. The evaporitic facies grades eastward (Fig. 24) into what Sandberg (1965) regards as a nearshore evaporitic facies; this is here called the argillaceous dolomite facies. It consists chiefly of greenish gray dolomitic shale in the lower part and thin-bedded brecciated light gray to buff and brownish gray argillaceous dolomite, with greenish shale partings, in the upper part. Brecciation, mud cracks, ripple marks, intraclasts, and dolomite pseudomorphs after halite suggest that this facies was somewhat evaporitic; but it lacks the massive nonbedded brecciated appearance of the typical evaporitic facies farther west.

The argillaceous dolomite facies forms most of the Logan Culch-Trident interval between the evaporitic facies to the west and the silty facies to the east (Fig. 24). It also underlies the evaporitic facies in west-central Montana and along the Wyoming-Idaho border (Fig. 23). A similar silty argillaceous and commonly variegated unit occurs at the base of the Three Forks in the Sweetgrass arch area, where Hurley (1962) calls it the Calmar red shale. In western Wyoming the evaporitic
facies grades northeastward into argillaceous dolomite and local lenses of solution breccia occur in the middle of the Three Forks in the Teton Range. The argillaceous dolomite facies is mostly equivalent to the Logan Gulch Member, but it may include some beds of the Trident Member in southern Montana.

The green shale facies (Fig. 25) is restricted to southwest, west, and north of the Logan, Montana area. The southernmost exposures are in the Greenhorn and Snowcrest Ranges east of Dillon, Montana. The facies consists of dark (usually greenish) calcareous fossiliferous clay shale and occurs entirely within the Trident Member as proposed by Sandberg (1965). A thickness of 250 feet is reached for this marine deposit northwest of Logan, Montana.

The green shale facies changes southeastward to relatively pure carbonates, as was suggested by McMannis (1962). Thin tongues of limy carbonate appear above and below the green shale, and these intertongue eastward into dolomitic rocks. The carbonate facies is characterized by medium to dark gray very finely crystalline dense limestone and dolomite which are in most places argillaceous and silty and weather to a light gray or buff color. In Montana, the carbonate facies may grade eastward into the upper part of the argillaceous dolomite facies. On the Tendoy dome in southwestern Montana, the typical carbonate facies occurs below a thin green shale unit. If this carbonate is a facies of the remaining green shale to the north, Logan Gulch equivalents may be missing on the Tendoy dome. A reddish zone at the base of the Three Forks in southwestern Montana and thinness of the Birdbear Member in the same area also suggest some erosion
Fig. 25. Lithofacies map of middle third of Three Forks Formation (mostly Trident Member)
between Jefferson and Three Forks deposition and perhaps slight uplift of the Tendoy dome. The carbonate facies also crops out in the Snake River Range along the Wyoming Idaho border (Fig. 25) and is probably continuous with similar rocks in Montana west of Yellowstone Park.

**Areal distribution.** The Logan Gulch-Trident interval (Fig. 26) is present in southwestern Montana and western Wyoming and increases in thickness westward. Pre-Madison erosion resulted in rapid thinning near the present eastern edge. The western limit of the Three Forks Formation may also be due to pre-Madison erosion following uplift that accompanied the latest Devonian Antler orogeny in Nevada and western Idaho. The westernmost exposure of the Three Forks in Montana is along Foster Creek near Anaconda where gray limestone and calcareous siltstone overlie the Jefferson. No Three Forks rocks are known above the Jefferson west of a line extending southwest from Anaconda, Montana to central Idaho (Fig. 26). In northern Montana the western edge of the Three Forks appears to lie near the eastern front of the overthrust belt.

The Logan Gulch and Trident Members are continuous northward with the "Potlatch" anhydrite and Three Forks "restricted" shale of Hurley (1962) in northwest Montana. In the Williston basin and southern Saskatchewan (Fig. 4) are similar lithologic divisions.

Southwest of the Tendoy dome, no sections of the Three Forks Formation were measured by the writer and little information has been published. Scholten and Hit (1962) report that the formation becomes less shaly and dolomitic westward, where it is mainly dark gray argillaceous limestone. Estimated thicknesses of as much as 350 feet have been reported.
Fig. 26. Isopach map of Logan Gulch and Trident Members of the Three Forks Formation
Scholten (1957) found that uplift in Early to Middle Mississippian time raised the southern Beaverhead and Lemhi Ranges resulting in erosion of Three Forks rocks. Overlying the Three Forks Formation in central Idaho is dark nonfossiliferous shale and sandstone of the Early (?) Mississippian Milligen Formation, which thickens westward as the underlying Devonian rocks thin by erosion.

In northeastern Utah the Three Forks Formation crops out at Laketown Canyon (Fig. 16) where it appears transitional between rocks characteristic of the shelf and those of the miogeosyncline. Here the Three Forks is mostly gray to buff very finely crystalline limestone containing local algal stromatolites and greenish to red calcareous mudstone. Floating sand grains are abundant in the mudstone, and solution breccias occur at several intervals. The Three Forks locally forms a reddish slope and is sharply overlain by the Lodgepole Limestone of the Madison Group.

Beirdneau Formation

Description. Rocks between the Jefferson and Madison carbonates in the Wasatch and Bear River Ranges are included in the Beirdneau Formation. This unit was originally named the Beirdneau Sandstone by Williams (1948) for exposures near the base of Beirdneau Peak on the north side of Logan Canyon, Utah. Near the type locality the Beirdneau is medium gray to pale brown dense very finely crystalline dolomite, commonly argillaceous, silty, and sandy. Halite casts, mud cracks, ripple marks, and floating sand grains are common. Two ledges of quartzitic sandstone appear in the lower half, but sandstone is not
the dominant rock type. A ledge-forming unit referred to informally by Williams (1943) as the "contact ledge" appears at the top of the Beirdneau Formation and below the Leatham Formation. Rock types in the Beirdneau Formation are distinctly different from those of the underlying Jefferson Formation. Only a few very thin beds of dark fetid dolomite occur at widespread intervals within the Beirdneau. The term Beirdneau Formation should be applied to light-colored sandy Devonian carbonates above the Jefferson Formation in the miogeosyncline.

**Stratigraphic correlation.** Correlation of the Beirdneau and Three Forks Formation is shown in Figures 16 and 21. Both formations are underlain by dark saccrroidal bituminous dolomite of the Jefferson Formation. The Beirdneau Formation in the Wasatch Range is overlain disconformably by the Leatham Formation, correlated lithologically and faunally by Holland (1952) with the Sappington Member of the Three Forks Formation in Montana. The Beirdneau Formation is thus equivalent to the Logan Gulch and Trident Members of the Three Forks Formation, below the Sappington Member.

**Distribution.** The sandy carbonates of the Beirdneau Formation are really restricted to the miogeosyncline on the upper plates of the Willard and Paris thrust faults (Fig. 22) in northeastern Utah and southeastern Idaho. This includes the Bear River and Wasatch Ranges and the area to the west. Argillaceous carbonates of the Three Forks Formation lie to the east. South of the Willard thrust fault the Three Forks Formation rests on pre-Devonian rocks at Durst Mountain. The Three Forks-Beirdneau rocks extend southward beyond the known
limit of the Jefferson Formation and lap over the Utah arch where thin equivalent strata are called the Victoria Quartzite and Pinyon Peak Limestone. The Victoria and Pinyon Peak units form a completely gradational sequence according to Brooks (1959), with the name Victoria Formation applied to the predominantly clastic lower portion. The Victoria forms a basal transgressive sand across the Utah arch. Equivalence of the entire Pinyon Peak to the Beirneau and/or Leatham Formations is not certain. The Three Forks equivalents extend south of the Uinta Mountains into Colorado as the Chaffee Formation.

In southeastern Idaho, the Beirneau Formation consists mostly of buff to medium gray dense silty limestone. Two sandstone zones in the lower half (Fig. 21) correspond to similar zones in northeast Utah. The areal distribution of calcareous and dolomitic facies of the Beirneau Formation is not known.

**Utah Arch**

The Utah arch began as a high in pre-Devonian time. Lower Devonian seas west and north of the arch deposited the Sevy Dolomite and equivalent nearshore Water Canyon Formation (Fig. 27). Following a period of erosion, the seas returned in late Middle Devonian and early Late Devonian time, depositing the Jefferson Formation and its dark-colored dolomite equivalents far east into Wyoming. Sand eroded from the emergent Utah arch was deposited sporadically in the upper half of the Jefferson in northern Utah. The southern extent of Jefferson rocks on the Utah arch is largely due to depositional onlap, but may be affected by erosion that immediately followed Jefferson
Fig. 27. Schematic cross section of Devonian System in northeastern Utah
deposition. According to Rigby (1959), local uplift and erosion at the end of Jefferson deposition was intensive in the Stansbury Range (Fig. 22). Much of the Jefferson equivalent was removed, producing the Stansbury conglomerate on the flanks of the uplift. North of the Utah arch the unconformity at the top of the Jefferson is less notable. The sharp contact everywhere between the Jefferson and overlying detrital rocks suggests a hiatus before Three Forks deposition, during which major uplift of the Utah-Transcontinental arch took place. After Three Forks-Beirdneau deposition on the Utah arch (Fig. 27) there was a hiatus before deposition of the Lestham Formation. Erosion in pre-Madison time removed large parts of formerly widespread Devonian units in northeastern Utah, western Wyoming, and northward.

Sappington Member

The Sappington Member of the Three Forks Formation was originally regarded by Sloss and Laird (1947) as a sandy facies intertonguing faunally and lithologically with the underlying Three Forks rocks. Recent detailed work by Gutschick, Suttner and Switek (1962) and Sendberg (1965) shows the Sappington resting disconformably on the lower Three Forks. Additional work on Sappington rock types has been done by Holland (1952), McMannis (1955), Gutschick and Perry (1957), and Achauer (1959).

Nine informal stratigraphic units, lettered A to I in ascending order, were designated by Gutschick, Suttner, and Switek. The lower black shale, which rests unconformably on the underlying Trident Member, consists of three distinctly different shales, A, B, and C. Unit D is
a thin fossiliferous green-gray shale. Units C and D are found throughout west-central Montana despite their thinness (6 inches and 2 inches respectively). Unit E, an algae-sponge biostrome, has a great diversity of fossils including Syringothyris. The algal nodules commonly have *Rhipidomella* as a nucleus. Unit F is a siltstone. Unit G is a dark greenish gray shale, called the middle shale unit. Unit H is a pale yellow-orange cliff-forming siltstone unit with numerous sedimentary structures and animal burrows. Unit I is a black shale, which transgresses the entire Three Forks Formation and is here regarded as a separate unit.

The lower shales represent shallow partially restricted marine and lagoonal conditions following retreat of the Three Forks sea. Gutschick, Suttner, and Switek believe the algae-sponge biotope formed in shallow marine water on a flat shelf. Muddy and silty tidal flats, with deltaic distributaries, are thought to be responsible for the siltstones.

Although the Sappington Member is best known in southwestern Montana, its lateral equivalents are probably present as far south as northern Utah. The Leatham Formation was named by Holland (1952) at Blacksmith Fork Canyon in northeastern Utah, and correlated lithologically and faunally with the Sappington in Montana. At the type locality, it consists of 76 feet of shale, sandy shale, siltstone, and nodular limestone overlying the Beirdneau Formation. The Sappington appears to extend across the Tendoy dome and southward into Idaho. No Sappington is known in outcrops of western Wyoming, owing to pre-Madison erosion in this area. A 15-foot siltstone at the top of a
thick Three Forks section on Baldy Mountain, Snake River Range, Idaho, may belong to the Sappington Member. The distribution of the Sappington and its equivalents, as well as comparison with areal distribution of other units is shown in Figure 31. The western edge of the Sappington may also have been restricted by pre-Madison erosion. The Sappington Member appears to be confined to the central part of a north-south Late Devonian trough whose eastern and western edges were affected by pre-Madison erosion. Thickness of the Sappington Member (McMannis, 1962, Plate XIV) is greatest in the Three Forks area.

The Sappington Member has been correlated by Sandberg (1965) with the Exshaw Shale in northwest Montana and southern Alberta (Fig. 4) and with the lower black shale and middle siltstone of the Bakken Formation in southeastern Alberta and southwestern Saskatchewan.

Age of Three Forks Formation

Peale (1893) designated the formation as probably Late Devonian in age. Fossils have been found in the shales and upper limestone of the Trident, and in the Sappington Member. Raymond (1907, 1909) found that the lower shales are definitely Late Devonian, but that fossils near the top of the sandstone (Sappington Member) include Mississippian types. Thus, the uppermost beds of the Three Forks Formation continue into the Lower Mississippian. A detailed study of the mollusks and brachiopods by Haynes (1916) confirmed this conclusion, and it has been reiterated by Robinson (1963) on the basis of detailed fossil collections in the Three Forks area. The Devonian-Mississippian boundary can be placed somewhere in the generally unfossiliferous
siltstones of units F, G, and H near the top of the Sappington. A recent disagreement is on whether the Trident and Sappington Members intertongue lithologically and faunally. Sloss and Laird (1947) found evidence of such stratigraphic intertonguing, and their conclusion is followed by Sloss and Moritz (1951), Rau (1962), and Robinson (1963). Sloss and Laird thought that there is an alteration of faunas controlled by lithofacies, and that the Cyrtospirifer fauna characteristic of the Trident Member may extend upward into the Syringothyris fauna of the Sappington Member. Although evidence is not conclusive, Robinson (1963) believes that extension of a faunal range due to a favorable persisting lithotope may be possible.

Crickmay (1952) first noted the regional faunal and lithologic break between the Sappington and underlying Three Forks shales. He concluded that Cyrticopsis in the Sappington had been misidentified as Cyrtospirifer which is limited to the underlying Trident Member. He also found a persistent black shale at the base of the Sappington which overlies an unconformity. A sharp lithologic and faunal break between the Trident and Sappington units in west-central Montana was found by McMannis (1955). Recent detailed stratigraphic work by Gutschick, Suttner, and Switek (1962) demonstrates that the Sappington lies unconformably on older Three Forks rocks. Some siltstones that have been found within the Trident shales by Sandberg (1965) may have been mistaken for the Sappington by earlier workers. The possibility of mixing of the Cyrtospirifer and Syringothyris faunas is yet unanswered. There has been little paleontologic work on the Three Forks Formation away from the type area. The fossiliferous Trident green
shales are found mainly near the type section, whereas the widespread Logan Gulch Member is unfossiliferous. Faunal lists have been prepared for some local areas and compared with the original Three Forks fauna described by Haynes (1916) and Raymond (1907, 1909). Three Forks faunas have been described by McMannis (1955) from the Bridger Range; Robinson (1963) from the Three Forks area; Klepper et al. (1957) from the southern Elkhorn Mountains; Richardson (1941) from northeastern Utah; Baldwin (1943) and Ross (1961) in the Lemhi Range, Idaho; and Ross (1947, 1962) from the Lost River Range. No fossils have been reported from the Beirdneau Formation, but brachiopods have recently been found in the Contact Ledge Member near the top of the formation in the Fish Creek Range of southeastern Idaho.

Although previous fossil identifications may have been consistent, little is known of their stratigraphic position, and no attempt was made to compile a complete list for regional dating. A Devonian faunal compilation was made by Warren and Stelck (1956) in western Canada where more information is known. They have illustrated a succession of Devonian faunas which should prove useful for comparison and in regional dating of various lithologic units.

The Trident Member has been generally assigned to the Platylymenia-Stufe (to III-IV) ammonoid zone (Fig. 30) of middle Famennian age. Sandberg (1963b) assigns the Logan Gulch Member to the Cheiloceras-Stufe (to II) ammonoid zone of earliest Famennian age, and the Sappington Member to the Clymenia (to V) and Wocklumeria (to VI) zones of upper Famennian age and the lower part of the Gattendorfia (cu I) zone of the Touraisian (Early Mississippian) stage of Europe.
Gutschick, Suttner, and Switek (1962) correlate the fauna of the Sappington algae-sponge biostrome unit E with the Louisiana limestone of the Mississippi Valley, whose age is latest Devonian Wocklumeria-Stufe (to VI). Age of the siltstones of units F, G, and H was given by the same authors as Early Mississippian.
DARK SHALE UNIT

A dark shale unit informally named by Sandberg (1963b) is present over much of western Wyoming and southern Montana. This thin unit is overlain by the Madison Limestone and is separated from various underlying Devonian rocks by a regional unconformity. The reference section described by Sandberg is at Clarks Fork Canyon in the southeastern part of the Beartooth Mountains (Fig. 28).

The dark shale unit is a marine sequence of dark gray carbonaceous shale and mudstone and yellowish brown silty dolomite. Field identification is aided by the presence of black phosphatic pellets, carbonaceous plant debris, glauconite, calcite nodules, worm impressions and burrows, Taphurus "swash marks," fish plates and teeth, large conodonts, echinoids, clay intraclasts, and hematite. The basal few inches are locally siltstone or sandstone containing reworked pebbles.

Dolomite lenses at many localities occur within the dark shale unit, but can be differentiated from dolomite beds in the Jefferson Formation. Dolomite in the dark shale unit is yellowish brown and usually is argillaceous, silty, and calcareous, and contains abundant crinoids. This silty crinoidal dolomite locally directly underlies typical black shales, but cannot be correlated laterally with dolomite beds in the Jefferson Formation (Figs. 11, 14, and 15). Because it differs in stratigraphic position and lithology from dolomite in the
Fig. 28. Type section of dark shale unit
Jefferson, it has been included in the dark shale unit. For instance, in the southern Absaroka Range 15 to 20 feet of this light-colored dolomite directly underlies a very thin dark shale and contains poorly preserved crinoids with long stems, brachiopods, blastoids, fenestelloid bryozoans, and possible ostracods. Dolomite strata in the dark shale unit thicken eastward as the black mudstone and shale disappear.

The basal 5 to 10 feet of the Madison overlying the dark shale unit is silty, carbonaceous, and crinoidal in most places. In the southern Absaroka Range yellowish gray to pinkish crinoidal dolomite overlies black mudstone and extends upwards for 30 feet or more before typical Madison carbonates are reached. Eastward in Wyoming where the black shale and mudstone disappear, it is difficult to differentiate the Jefferson, dark shale, and Madison carbonates.

The Englewood Formation in the Black Hills is lithologically and faunally similar to the dark shale unit (Klapper and Furnish, 1962; and Sandberg, 1963b). Perhaps this name should be applied to silty crinoidal dolomites at the base of the Madison and other rocks above the regional unconformity regardless of the amount of black shale locally present.

At the dark shale unit reference section the dark shale unit thins 6 feet in a lateral distance of 150 feet, owing to disappearance of rock from the top of the unit. A thin breccia at the base of the Madison Limestone at Warm Spring Canyon, in the northern Wind River Mountains, lends additional evidence for a hiatus between deposition of the dark shale unit and the Madison Limestone.
The dark shale unit is present in western and northern Wyoming and southern Montana (Fig. 29). Possible equivalents occur in extreme western Montana, central Idaho, and northeastern Utah. The unit is thickest in a trough-like area extending north-eastward from the Green River basin, approximately along the Birdbear-Three Forks eastern erosional edge. Westward across Wyoming and Montana the unit is generally less than 10 feet thick and truncates progressively younger rocks of the Three Forks Formation. Sandberg (1963b) has traced the unit northeastward in the subsurface of Montana and eastward in northern Wyoming through the Bighorn Mountains. A broad area from the western Green River basin to western Montana appears to lack the dark shale unit. Local pockets of dark shale may have accumulated in lows on the underlying erosion surface near the zero edges shown in Figure 29.

In the Philipsburg area of western Montana dark gray to black shale was found locally at the base of the Lodgepole Limestone by Emmons and Calkins (1913) and McGill (1959). A Kinderhookian age based on conodonts was determined by Cooper and Sloss (1943). This shale may be gradational upwards into argillaceous limestone of the Paine Member of the Lodgepole Limestone. In central Idaho the Milligen Formation described by Ross (1962) consists mostly of black carbonaceous argillite with minor beds of quartzite and limestone. It was spread eastward as a result of uplift accompanying the Antler orogeny. These shales have not been dated, but they underlie the Lodgepole Limestone and appear to be similar in age and origin to the basal Lodgepole shales of western Montana. In northeastern Utah, a black shale unit that immediately underlies the Lodgepole Limestone may be
Fig. 29. Isopach map of dark shale unit
equivalent to the thick shales in Idaho and the thinner dark shale unit to the northeast.

Information on the age of the dark shale unit in western Wyoming and southern Montana is the result of work by Klapper (1962) and Sandberg (1963b). The age ranges from Late Devonian (Fig. 30), equivalent to the Clymenia-Stufe (to V) of the European Famennian stage, to earliest Mississippian, equivalent to the lower part of the Gattendorfia-Stufe (cu I) of the European Tournaisian stage. The dark shale unit becomes younger westward. In the eastern Wind River Range, Bighorn Mountains, and eastward, the unit is latest Devonian and earliest Mississippian (Sandberg, 1963b); in the northern Wind River Mountains, Absaroka Range, Beartooth Mountains, and westward into Wyoming and Montana, it appears to be entirely Early Mississippian.

In the Black Hills region Klapper and Furnish (1962) found the equivalent Englewood Formation to be Late Devonian and Early Mississippian. The basal Lodgepole shales of extreme western Montana were determined to be Early Mississippian (Kinderhookian) by Cooper and Sloss (1943).
<table>
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<tr>
<th>SYSTEM</th>
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<th>AMMONOID ZONE (STUFE)</th>
<th>FORMATION AND MEMBER</th>
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<td>TOURNAI-SIAN</td>
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<td>Platycolemna (to III IV)</td>
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<td>Mantiloceras (to I)</td>
<td>BIRDBEAR MEMBER</td>
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**Fig. 30.** Age of Devonian rocks
SUMMARY

The Jefferson Formation was measured and described at 75 localities in southwestern Montana, western Wyoming, southeastern Idaho, and northeastern Utah. It is composed mainly of dark fetid dolomite and limestone, easily differentiated from various underlying light-colored rocks and from the overlying Three Forks Formation. In the Late Devonian shelf area of Montana and western Wyoming, the Jefferson Formation can be divided into a Lower Member and Birdbear (upper) Member.

The Lower Member consists of dolomite, limestone, and thin detrital units. It has been traced into the Duperow Formation in the Williston basin. The detrital beds are lettered from A to I in descending order beginning with a thick detrital unit that separates the Birdbear and Lower Members throughout Montana and Wyoming. The detrital units increase in number and thickness toward central Wyoming.

In the Wind River Mountains, southeastern Absaroka Range, western Owl Creek Mountains, and adjacent basins of west-central Wyoming, the Birdbear Member and overlying Three Forks Formation have been removed by latest Devonian and Early Mississippian erosion, leaving only the Lower Member of the Jefferson Formation, which through original and popular use is known as the Darby Formation. Intraformational correlation, based mainly on detrital beds and carbonate ledge-forming units, allows the Darby Formation to be correlated exactly with the Lower Member of the Jefferson Formation.
The Jefferson Formation thickens into the miogeosyncline in western Montana, Idaho, and northern Utah, where it consists of dark gray dolomite, some limestone, and a few detrital beds in the upper half. In western Montana the Jefferson is underlain conformably by the Maywood Formation, a basal detrital unit that transgresses and thins southeastward.

The lower half of the Lower Member in west-central Montana and westermost Wyoming is mainly limestone and is referred to informally as the lower limestone unit. Over the Tendoy dome in southwestern Montana, the Lower Member thins markedly, and the entire Jefferson is locally absent.

The Birdbear Member is a massive ledge-forming dolomite, generally 60 to 115 feet thick. This member has been traced from its type locality in the Williston basin.

The Jefferson Formation is present in northern and western Wyoming (Fig. 31) and far south into the Green River basin. The southeastern edge is the result of pre-Madison erosion, but thinning near this edge is also due to depositional onlap and thinning of individual units. The Jefferson extends northward throughout most of Montana, eastward into the Dakotas, and far northward into Canada. The western limit of Jefferson rocks (Fig. 31) is the result of pre-Madison erosion in central Idaho and northward along the Idaho-Montana border. From northern Utah the Jefferson equivalents extend westward into eugeosynclinal facies in central Nevada. The Jefferson Formation disappears mainly by onlap southeastward over the Utah arch, a Devonian high that extended a short distance west of the present Uinta arch.
Fig. 31. Areal distribution of stratigraphic units in western Wyoming and adjacent areas
The Jefferson Formation contains few diagnostic fossils except in rare undolomitized areas. An early Late Devonian age equivalent to the Frasnian stage in Europe is assigned throughout the shelf area. In the miogeosyncline of southern Idaho and northern Utah, fossiliferous beds near the base of the Jefferson are Late Devonian, but the lowest beds may be latest Middle Devonian.

The Three Forks Formation is more limited in areal distribution (Fig. 31) than the Jefferson because of pre-Madison erosion. The Three Forks crops out in southwestern Montana and western Wyoming. Equivalent strata in the miogeosyncline of northeastern Utah and southeastern Idaho are included in the Beirnesau Formation. Three members of the Three Forks Formation can be distinguished near the type section at Logan, Montana. The lowest member (Logan Gulch) contains mostly evaporite solution breccias. The middle member (Trident) is mostly green fossiliferous shale. The upper member (Sappington) disconformably overlies the lower part of the Three Forks Formation and consists of dark shale, siltstone, and sandstone. The Sappington Member is generally restricted to southwestern Montana (Fig. 31), although equivalents have been found in eastern Idaho and in northeastern Utah (Leatham Formation). The lower two members of the Three Forks are more widespread, but cannot be differentiated with certainty southeast of the Logan type section. Five rock facies are used to show areal distribution of rock types within the Logan Gulch-Trident interval. In the lower third of the Three Forks (mostly equivalent to the Logan Gulch Member) are two large areas of evaporite facies. One is in west-central Montana and continues northward; the other is along the Wyoming-Idaho
border. The evaporite facies grades eastward into an argillaceous dolomite facies and this in turn becomes a near-shore silty facies near the present eastern erosional edge of the Three Forks (Fig. 31). The middle third of the Three Forks (mostly equivalent to the Trident Member) is more restricted in distribution. A green shale facies occupies most of this interval northwest of Logan, Montana, and grades southeastward into a carbonate facies. The Logan Gulch and Trident Members have been assigned a middle Late Devonian age (Fig. 30) equivalent to the early part of the Famennian stage of Europe. The Sappington Member is latest Devonian and earliest Mississippian (Fig. 30) equivalent to the latest Famennian and earliest Tournaïsian stages of Europe.

A dark shale unit overlies a regional unconformity that cuts across various Jefferson and Three Forks rocks. The unit is characterized by dark gray carbonaceous shale, mudstone, and silty crinoidal dolomite. A thick trough of the dark shale unit lies near the Birdbeard-Three Forks erosional edge and trends northeastward across Wyoming from the Green River basin. In western Wyoming and southwest Montana the unit is less than 10 feet thick. This unit is not present in a band from the western Green River basin northward to western Montana. Its age is latest Devonian in central Wyoming to Early Mississippian in western Wyoming and southwest Montana (Fig. 30). Possibly partly equivalent, but much thicker, Early Mississippian dark shales are present in western Montana, central Idaho, and northeastern Utah.
APPENDIX

Maps, Published Material, Location
and Information on Sections
Measured by the Writer

Idaho

Bannock County

Monroe Canyon            NE 32-7S-40E
On southwest spur of mountain north of Monroe Canyon
Portneuf 15' quadrangle
Mansfield, 1929
Jefferson covered at base, Three Forks poorly exposed at top

Bancroft                      2-10S-39E
Along Great Basin-Columbia River divide beginning at
west section line
Bancroft 15' quadrangle
Jefferson, Beirdneau and Contact Ledge

Bonneville County

Baldy Mountain             7 & 17-1N-45#*
Cliffs below peak of Baldy Mountain, and on south wall
of Palisades Creek
Irwin 30' quadrangle
Gardner, 1944
Upper half of Lower Member, Birdbear, Three Forks and
Sappington (?) on Baldy Mountain, lowest
Jefferson along creek

Stouts Mountain           SW NE 36-3N-43E
On spur extending down toward head of Golpher Canyon
Garns Mountain 15' quadrangle
Lower Member and Birdbear exposed, Three Forks mostly covered

Caribou County

Soda Springs               SW SW 28-8S-41E
From east side of road toward peak 6924
Soda Springs 15' quadrangle
Armstrong, 1953
Jefferson well exposed, Beirdneau present

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Custer County

Grand View Canyon 23 & 26-12N-20E
Along highway
Bayhorse 30' quadrangle
Ross, 1934, 1937
Jefferson and Three Forks Formations

Fremont County

Targhee Peak NE 14-16N-43E
On cliffs overlooking Targhee Creek at end of logging road
Gallatin National Forest map
Sloss and Moritz, 1951
Lower Member, Birdbear, Three Forks, dark shale unit

Montana

Beaverhead County

Wise River NE 14-1S-11W
About 2 miles southeast of the town of Wise River
Wise River 7.5' quadrangle
Maywood Formation

Argenta SW NE 35-6S-11W
Across road between Ermont mine no. 2 and no. 19
Ermont 7.5' quadrangle
Jefferson exposed, Three Forks covered

Ashbough Canyon 27-9S-8W
On northwest and southeast side of canyon
Dillon 1:250,000 quadrangle
Sloss and Moritz, 1951
Jefferson exposed, Three Forks partly covered

Horse Prairie Creek SW SW 31-9S-10W
In small canyon in Jefferson hogback
Eli Spring 7.5' quadrangle
Sloss and Moritz, 1951 (Cedar Creek section)
Jefferson exposed, Three Forks partly covered

Kate Creek SW NE 27-12S-11W
On west side of McBride Creek
Map by Scholten, et al., 1955
Jefferson exposed, Three Forks covered
Sheep Mountain  SE SE 26-14S-1W
On west side of cirque below peak 9683
Upper Red Rock Lake 15' quadrangle
Sloss and Moritz, 1951
Jefferson and Three Forks well-exposed

Deer Lodge County

Sugarloaf Mountain  NW 27-3N-11W
Along Crooked John Creek just south of deserted town
Dickie Peak 7.5' quadrangle
Noel, 1956
Jefferson highly faulted, Three Forks covered

Foster Creek  6-5N-12W
Along ridge west of creek
Philipsburg 30' quadrangle
Jefferson and Three Forks metamorphosed

Galatin County

Logan  SE 25-2N-2E
North side of Gallatin River northeast of Logan
Manhattan 15' quadrangle
Peale, 1893; Sloss and Laird, 1947; and Sandberg, 1962
Mywood, Jefferson, Three Forks, and dark shale unit

Fairy Lake  SW SW 22-2N-6E
North side of cirque from divide toward peak 9559
Sedan 15' quadrangle
McMannis, 1955, 1962
Jefferson, Three Forks and dark shale unit well-exposed

Goose Creek  NW 20-3S-4E
On west bank of Goose Creek
Anceney 15' quadrangle
McMannis, 1962
Jefferson Formation, faulted against Precambrian at top

Blacktail Mountain  SE SW 9-3N-5E
On north side of Rocky Canyon
Maudlow 15' quadrangle
McMannis, 1955, 1962
Lower Member and Birdbear well-exposed, Three Forks covered

Mystic Lake  NE 36-3S-6E
West side of creek south of dam; lower part of section
exposed along logging road one half mile south of dam
Bozeman Pass 15' quadrangle
McMannis, 1962; Roberts, written communication, 1963
Jefferson, Three Forks and dark shale unit
Scow Creek NW 34-4S-4E
East of Stormcastle trail, Maywood in section 28
Carnet Mountain 15' quadrangle
McMannis, 1962; Sandberg and McMannis, 1964
Maywood, Jefferson, Three Forks and dark shale unit

Hyalite Canyon NW NW 9-4S-6E
Along stream west of gravel road 1.5 miles south of camp
Bozeman Pass 15' quadrangle
McMannis, 1963
Upper part of Lower Member and Birdbear well-exposed

Dudley Creek SE NE 32-6S-4E
Cliffs west of highway one half mile south of Dudley Creek
Spanish Peaks 15' quadrangle
McMannis, 1962
Jefferson exposed, Three Forks covered

Bacon Rind Creek SE 22-10S-5E
On cliffs one half mile north of intersection of Migration Creek and Bacon Rind Creek, west of Yellowstone Park
Tepee Creek 15' quadrangle
Jefferson, Three Forks, and dark shale unit well-exposed

Cabin Creek NE 15-11S-3E
West side of creek along foot trail
Hebgen Lake 15' quadrangle
Sloss and Moritz, 1951
Lower Member faulted at top

Granite County

Rock Creek NE 29-4N-14W
Along East Fork of creek and cliffs to the east
Philipsburg 30' quadrangle
Kindle, 1908; Emmon and Calkins, 1913; and Poulter, 1957
Maywood and Jefferson Formations, basal Lodgepole shale

Boulder Creek SW SW 14-8N-13W
Along north side of road; type Maywood on bluffs SE sec. 23;
top of section north of Princeton SW SE sec. 24
Philipsburg 30' quadrangle
Kindle, 1908; Emmon and Calkins, 1913; and McGill, 1959
Maywood and Jefferson Formations, basal Lodgepole shale

Jefferson County

Cottonwood Canyon NW 32-2N-2W
Along north side of road beginning near tunnel
Jefferson Island 15' quadrangle
Maywood and Jefferson Formations, faulted at top
Devils Fence          SE SW 28-5N-2W
On west flank of Devils Fence Ridge
Devils Fence 15' quadrangle
Klepper, et al., 1957
Maywood, Jefferson, and Three Forks, faulted at top

Madison County

Jordan Creek         SW NW 23-5S-1E
On north side of wooded ravine
Ennis 15' quadrangle
Jefferson and Three Forks Formations well-exposed

Baldy Mountain      SE NW 27-7S-3W
On spur north of peak 9533 (Baldy Mountain)
Varney 15' quadrangle
Jefferson well-exposed, Three Forks covered and faulted at top

Ruby Creek           SE NE 26-9S-2W
North side of Ruby Creek 1000 feet west of Beartrap Canyon mouth
Varney 15' quadrangle
Jefferson and Three Forks Formations

Sunset Peak          24-11S-5W
On ridge one mile west across valley from Sunset Peak
Beaverhead National Forest Map
Gealy, 1953
Jefferson, Three Forks and dark shale unit

Silver Bow County

Camp Creek            NW 20-2S-5W
North side of Camp Creek, 1000 feet west of dam
Melrose 7.5' quadrangle
Sloss and Moritz, 1951
Maywood and Jefferson well-exposed, Three Forks poorly exposed

Sweet Grass County

Baker Mountain        SW NW 35-3S-12E
On west side of road toward peak 5769
McLeod Basin 7.5' quadrangle
Base of Jefferson faulted out, Three Forks and dark shale unit

Park County

Livingston Canyon    NW 1-3S-9E
Along cliffs on east side of river
Brisbin 7.5' quadrangle
A. E. Roberts, written communication, 1963
Jefferson and Three Forks Formations and dark shale unit
Mission Creek
SW SW 6-35-11E
High on cliffs on northwest side of Mission Canyon
Livingston Peak 7.5' quadrangle
Tomlinson, 1927; Richards, 1958; McMannis, 1962
Maywood, Jefferson, Three Forks and dark shale unit well-exposed

Mill Creek
NW NE 13-68-9E
On southwest face of Castle Rock
Emigrant 15' quadrangle
Wilson, 1937; McMannis, 1962
Jefferson exposed, Three Forks covered

Cinnabar Mountain
NE SW 31-83-8E
On southeast edge of vertical beds of Devils Slide, Three Forks well-exposed in SE NW sec. 31
Miner 15' quadrangle
Wilson, 1934; McMannis, 1962
Jefferson and Three Forks Formations

Powell County

Elliston
SW SW 1-10N-7W
Along power line from crest of hill to southwest section corner
Elliston 15' quadrangle
Jefferson and Three Forks poorly exposed

Yellowstone National Park

Meridian Ridge
One mile north of Cooke Ranger Station and 1 mile southwest of Meridian Peak along the south face of Meridian Ridge
Cutoff Mountain 15' quadrangle
Sandberg, 1962a
Jefferson and Three Forks Formations and dark shale unit

Wyoming

Fremont County

Bull Lake Canyon
N 9-2N-4W
South wall of Bull Lake Canyon
Bull Lake West 7.5' quadrangle
Strickland, 1957; and Benson et al., in prep.
Beartooth Butte Formation, Darby Formation, dark shale unit

Trout Creek
SW SE 5-26-2W
On west side of peak 8407 south of Moccasin Lake Road
Moccasin Lake 15' quadrangle
Darby Formation
Dinwoody Canyon, NW 12-4N-6W
Hays Park 7.5' quadrangle
Thomas, 1948; Strickland, 1957; Benson et al., in prep.
Darby Formation, dark shale unit

Crow Mountain, SW 36-7N-5W
One quarter mile west of road
Kirwin 30' quadrangle
Love, 1939; Thomas, 1948
Darby Formation

Sinks Canyon, NE SW 18-32N-100W
Discontinuous pockets in cliffs north of road
Fossil Hill 7.5' quadrangle
Strickland, 1957
Sandy lenses of Darby Formation

Jackets Fork, SW 25-41N-107W
North wall of canyon
Fremont Peak 30' quadrangle
Strickland, 1957; Benson et al., in prep.
Darby Formation and dark shale unit

Warm Spring Canyon, SW SE SE 36-42N-108W
Near top of canyon below peak 8416
Warm Spring Mountain 7.5' quadrangle
Andrichuk, 1956; Keefer, 1957; Strickland, 1957; Reeves, 1958
Darby Formation and dark shale unit

Horse Creek, SW SW 19-43N-106W
At excavation along roadside
Ramshorn Peak 7.5' quadrangle
Keefer, 1957
Darby Formation and dark shale unit

Windy Gap, SW SE 36-43N-106W
Along northwest flank of Black Mountain along Wiggins Fork
Indian Point 7.5' quadrangle
Love, 1939; Keefer, 1957
Darby Formation and dark shale unit

Du Noir River, 28 & 33-44N-108W
Along East Fork of Du Noir River near faulted anticline crest
Shoshone Pass 7.5' and Esmond Park 7.5' quadrangles
Keefer, 1957
Darby Formation and dark shale unit

Dundee Meadows, NE SW 10-44N-109W
Northwest side of meadow
Dundee Meadows 7.5' quadrangle
Darby Formation and dark shale unit
Brooks Lake               NE 3 -45N-110W
Ravine south of peak and just north of Cub Creek
Mt. Leidy 30' quadrangle
Darby Formation and dark shale unit

Hot Springs County

Merritt Pass               NE NW 2-7N-1W
In saddle near peak 8273
Bargee 7.5' quadrangle
Darby Formation poorly exposed

Lincoln County

Amerada Fossil Well        SE SW 23-21N-11W
Courtesy American Stratigraphic Company
Electric log and description
Jefferson and Three Forks Formations

Max Pray Gov't Barbari Well NE SE 23-26N-114W
Courtesy American Stratigraphic Company
Electric log and description
Jefferson and Three Forks Formations

LaBarge Mountain            SW 1-26N-114W
On southwest side of ridge, 2 miles north of farm
Preston, 1:250,000 quadrangle
Bertagnolli, 1942; and Osmond, 1962
Jefferson and Three Forks Formations and dark shale unit

Carter Meridian Ridge Well  SW SW 10-26N-115W
Courtesy American Stratigraphic Company
Gamma Ray-Neutron log and description
Two complete sections of Jefferson and Three Forks Formations

Bedford                    NE 26-34N-118W
South side of Strawberry Creek
Afton 30' quadrangle
Rubey, 1958
Jefferson Formation well-exposed, Three Forks covered

Snake River Canyon         SW 10-37W-118W
East side of ridge one half mile south of Ferry Peak,
1.5 miles north of road up Sheep Gulch
Jackson 30' quadrangle
Wanless et al., 1955; Roeskerman and Bardley, 1956
Jefferson and Three Forks Formations, some thrust faulting
Park County

Clarks Fork Canyon  NE NE 7-56N-103W
West side of hogback north of river
Deep Lake 15' quadrangle
Hughes, 1933; Leatherock, 1950; Andrichuk, 1956;
Sandberg, 1961b, 1963b
Beartooth Butte, Jefferson and Three Forks Formations,
and dark shale unit

Beartooth Butte  36-58N-106W (unsurveyed)
On southeast side
Beartooth Butte 15' quadrangle
Sandberg, 1961b
Beartooth Butte Formation, lower part of Jefferson Formation

Shoshone Canyon  SW NW 5-52N-102W
North wall of canyon, 2 miles east of dam on rock projection
just east of where secondary road passes under main road
Cody 15' quadrangle
Johnson, 1934; Stipp, 1947
Derby Formation and dark shale unit

Sweetwater County

Mountain Fuel U.P.R.R. Well No. 4  SW NE 11-19N-104W
Courtesy American Stratigraphic Company
Gamma Ray-Neutron log and core description
Derby Formation

Sublette County

Belco Ramsfork Well  SE SE 30-19N-115W
Courtesy American Stratigraphic Company
Electric log and description
Jefferson (faulted at base) and Three Forks Formations

Mobil Tip Top Well No. 22-19  NW NW 19-28 N-113W
Courtesy American Stratigraphic Company
Electric log and description
Jefferson and Three Forks Formations

California Deadline Ridge Well  SE SE 13-28N-115W
Courtesy American Stratigraphic Company
Gamma Ray-Neutron log and description
Jefferson and Three Forks Formations
Mt. Darby
Along east front of Mt. Darby
Afton 30' quadrangle
Birdbear Member, Three Forks Formation and dark shale unit

Steele Butte
At north end of Steele Butte outlier
Love, 1950 (map); Andrichuk, 1956
Darby Formation, poorly exposed at top

Sheep Mountain
Along ridge 1.5 miles northeast of peak of Sheep Mountain
Front Peak 30' quadrangle
Blackwelder, 1918; Richmond, 1945; Baker, 1946
Darby Formation and dark shale unit

Teton County

Hoback Canyon
On north wall of canyon one-third mile east of Stinking Springs
Jackson 30' quadrangle
Birdbear Member, Three Forks Formation and dark shale unit

Granite Creek
On southwest face of cliffs directly east of Granite Falls
Gros Ventre 30' quadrangle
Foster, 1947
Jefferson and Three Forks Formation

Glory Mountain
One mile northeast of Teton Pass in ravine on east side of peak
Grand Teton 30' quadrangle
Foster, 1947; Andrichuk, 1956
Jefferson and Three Forks Formations and dark shale unit

Taylor Mountain
Along ravine entering Coal Creek below peak to Taylor Mountain
Grand Teton 30' quadrangle
Wanless et al., 1955
Jefferson and Three Forks Formations and dark shale unit

Darby Canyon
Below entrance to Wind Cave at tributary fork 1 mile south of Darby Creek
Grand Teton 30' quadrangle
Birdbear Member, Three Forks Formation and dark shale unit

Teton Creek
Cliffs southeast of Boy Scout Camp, 1/4 mile east of falls
Grand Teton 30' quadrangle
Williams, 1955; Reeves, 1964
Jefferson and Three Forks Formations and dark shale unit
South Fork Buffalo River  NE NE 33-45N-111W
North of Blackrock Meadows, northwest side of ridge near top
Mt. Leidy 30’ quadrangle
Jefferson and Three Forks Formations

Soda Fork of Buffalo River  NW 27-46N-111W
On cliffs north of Soda Fork about 2 miles east of Buffalo Fork
Mt. Leidy 30’ quadrangle
Three Forks and dark shale unit well-exposed

Buffalo Fork  NW NE 31-46N-111W
Along north Buffalo Fork 1 mile west of junction with
Soda Fork
Mt. Leidy 30’ quadrangle
Wengston, 1956
Jefferson well-exposed, Three Forks and dark shale unit present

Berry Creek  SW 26-47N-116W
North side of Berry Creek south of Elk Ridge
Buckleberry Mountain and Grassy Lake Reservoir 15’ quadrangles
Iddings and Weed, 1899
Jefferson and Three Forks Formations covered near top

Yellowstone National Park

Crowfoot Ridge
West side of ridge below peak 9891 at head of Gallatin Creek
Mount Holmes 15’ quadrangle
Iddings and Weed, 1899; McMannis, 1962
Jefferson and Three Forks Formations

Utah

Cache County

Blacksmith Fork Canyon  SW 1-10N-11E
On north side of road toward the northeast
Logan 7.5’ quadrangle
Tomlinson, 1917; Holland, 1952; and Mullens and Izzett, 1964

Rich County

Laketown Canyon  SW 17-12N-6E
Along north wall of East Fork of Laketown Canyon on
abandoned road
Randolph 3’ quadrangle
Richardson, 1941
Jefferson and Three Forks Formations
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