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Title STRATIGRAPHY OF PART OF THE CROW INDIAN RESERVATION, BIG HORN COUNTY, MONTANA

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Nearly 1,300 feet of Paleozoic sedimentary rocks are exposed in the area northeast of the Pryor Mountains, Big Horn County, Montana. Overlying the Paleozoic strata are over 2,300 feet of Mesozoic sedimentary rocks.

The rocks of the area range in age from Mississippian to Early Cretaceous. Twelve formations were mapped, and the lithology, thickness, age, source rocks, and environment of deposition are discussed for each formation.

Of special interest is the Birdhead Sandstone Member of the Thermopolis Shale (Early Cretaceous). Lateral stratigraphic relationships of this sandstone indicate that a fluvial complex carried clastic material from the west and deposited it in a nearshore environment marginal to a delta. The detrital components and facies relationships indicate that the Birdhead is marginal to a western delta rather than to the eastern Newcastle Sandstone delta.

The structures are the result of uplifting and tilting of large crustal blocks. They were formed during the later part of the Laramide Orogeny in Late Cretaceous to Early Tertiary.

No structural or stratigraphic conditions appear to be favorable for the accumulation of oil and gas. Bentonite deposits in Early Cretaceous shales, although of industrial quality, are located in sites unsuitable for mining.

STRATIGRAPHY OF PART OF THE CROW INDIAN RESERVATION BIG HORN COUNTY, MONTANA

by

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INTRODUCTION

Location and Accessibility

Location

The area mapped is located approximately 30 miles southeast of Billings, Montana, and lies within the western part of Big Horn County (Plate 1). The area is included in the western part of the Crow Indian Reservation (Index Map, Plate 3). Specifically, the area includes all of T.5 S., Rs. 27 and 28 E., and the southern part of T.4 S., Rs. 27 and 28 E.

The northern limit of the thesis area is the boundary between Yellowstone County and Big Horn County. The Pryor Mountains form the southern boundary of the area.

There is nearly 3,000 feet of relief within the area. The lowest elevation, 3,800 feet, lies to the northwest near Deep Creek (Plate 3); while the highest point is the summit of North Pryor Mountain at 6,800 feet. The topography of the northern two-thirds of the mapped area is formed by flat, gently north-sloping plains interrupted only in the northeastern corner by flat-topped Woody Divide (Figure 1). In the southern part the dips of the strata steepen

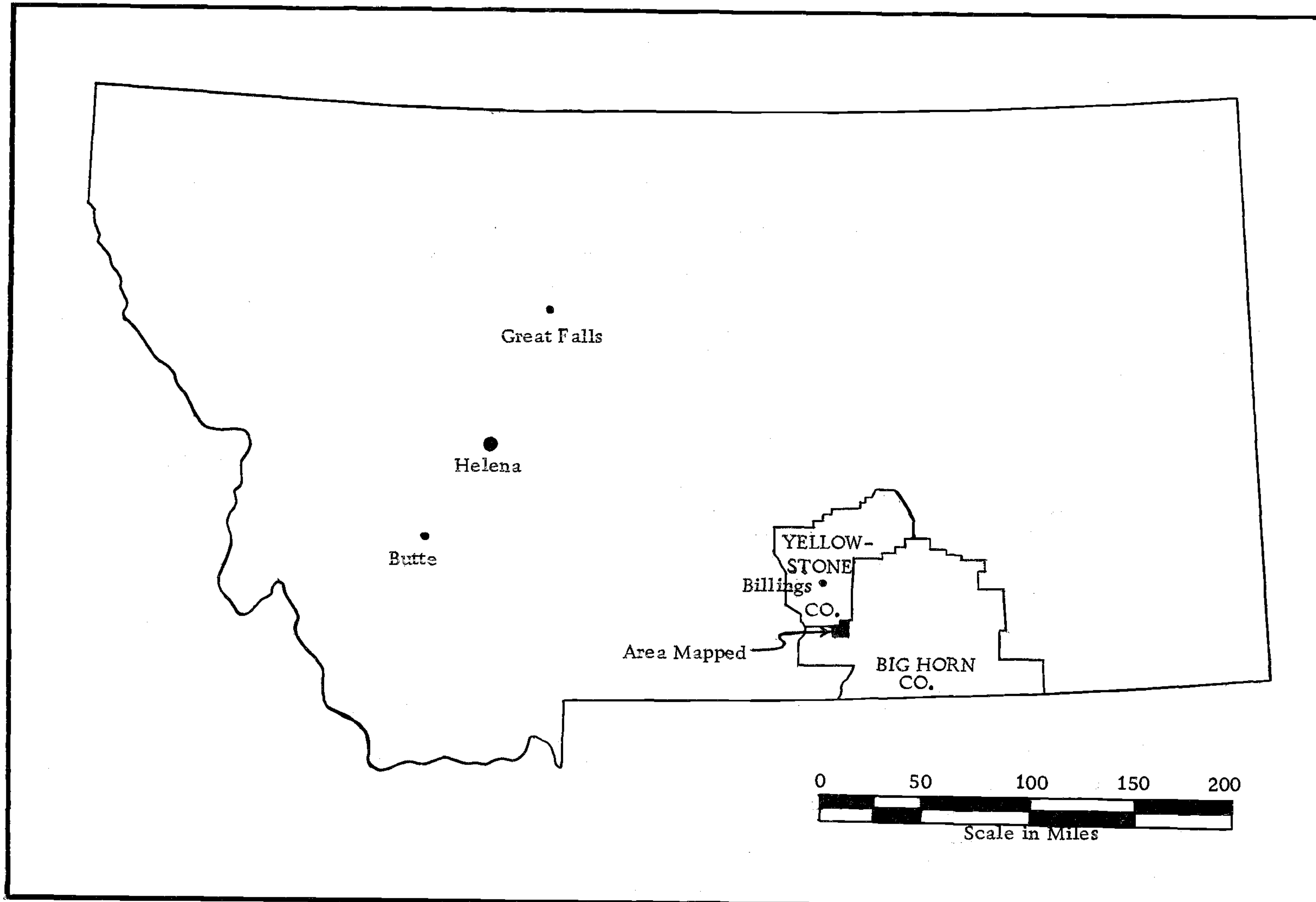


Plate 1. Map of Montana showing location of thesis area.

and the topography is formed by the Beauvais Creek Cuestas and Shively Hill Dome. North Pryor Mountain in the extreme southwestern corner of the thesis area rises abruptly above the plains and is the most prominent topographic feature in the area (Figure 2).

It is in this part of south-central Montana that many famous men of the "Old West" left their mark. Pryor Creek, from which the Pryor Mountains, Pryor Gap, and the town of Pryor gained their names, was named for Sergeant Pryor, one of the three sergeants of the Lewis and Clark Expedition. The town of Pryor, a subagency of the Crow Indian Reservation, was the home of Chief Plenty Coups, the last of the great Crow war chiefs. Will James, the famous writer-artist, located his ranch near the northeastern foot of Shively Hill Dome. The Bozeman Trail from Wyoming leads through the southern part of the thesis area along the northern edge of Shively Hill Dome and North Pryor Mountain. Some of the old wagon ruts are still visible on the trail.

Accessibility

The main approach to the area is from the northwest. U. S. Highway 87 leads east from Billings, Montana, to Hardin (Index Map, Plate 3). The Pryor Creek road, an all-weather road, makes a junction with U. S. Highway 87 approximately nine miles east of Billings. From the junction it proceeds south following Pryor Creek

FIGURE 1. The long, flat-topped north-south bench on the horizon is Woody Divide. In the right foreground the ridge rises from the north-sloping plains to form the north flank of Shively Hill Dome.

FIGURE 2. North Pryor Mountain in the southwestern corner of the thesis area. The fold and flatirons are formed in the Madison Limestone. Castle Butte Fault separates the plains from the mountain.

Valley to the town of Pryor. It then becomes a maintained gravel road at Pryor and continues south through Pryor Gap into Wyoming. The Blue Creek road from Billings joins the Pryor Creek road approximately 12 miles north of the town of Pryor. The Blue Creek road also has an all-weather surface. None of the roads mentioned above traverse the thesis area, but they are the major approaches.

Three main roads, all of which proceed east off of the Pryor Creek road, lead into the thesis area. These roads, as well as the connecting roads and trails, are dirt and are not maintained either by the reservation or the county. Two of the main roads follow the divides between East Fork Pryor Creek-Hay Creek and Deep Creek-Hay Creek. Both of these roads lead directly to ranches within the area. The third road approaches from the west out of Pryor and leads along the foot of the northern Pryor Mountains. This last road is least traveled.

It should be noted that normal travel is not possible during any type of wet or snowy weather because the roads rapidly become slick and muddy. Also because the roads and trails often ford creeks and coulees and because of the possibility of quick weather changes, a four-wheel-drive vehicle is advised at all times.

Purposes and Methods of Investigation

Purposes

Field and laboratory work was directed toward two specific objectives: (1) to map the surface geology, describe the stratigraphic units of the area, and delineate the major structures; (2) to study the environmental features of the Birdhead Sandstone and attempt to relate this unit to the Muddy and Newcastle Sandstones of Wyoming and Montana.

Methods of Investigation

The field study was initiated in mid-June, 1965, and completed in mid-September, 1965. The surface mapping was plotted on high altitude (1:60,000) aerial photographs obtained from Ammann International. This information was transferred to a photo mosaic constructed by Ammann International from high altitude photographs and enlarged to a scale of one inch equals 4,000 feet (1:48,000). There are no large scale topographic maps available for this area.

Stratigraphic sections were measured for all formations. The Birdhead Sandstone was measured at 20 localities within and adjacent to the thesis area.

Lithologic descriptions were recorded in the field for all traverses and accompany all measured sections. Gilbert's classification (68) is used for all sandstone descriptions. Carbonate rocks are classified according to the scheme suggested by Leighten and Pendexter (38).

Petrographic studies were made mainly of samples from the Birdhead Sandstone. Ten grain mounts and 30 thin sections were prepared and studied microscopically.

Previous Work

In past literature the thesis area has been investigated only on a reconnaissance basis. Several reports include all or part of the area in a discussion of regional geology. No previous attempt has been made to treat the mapped sector in detail.

Darton (17) mapped and described the geology southeast of the area in the Big Horn Mountains region. His work represents one of the first major attempts to map the geology of the northern Wyoming - south-central Montana region. Many of the formation names used in the thesis were proposed by Darton.

Thom *et al*. (63) mapped the entire Crow Indian Reservation and Big Horn County, Montana. This report includes the whole thesis area but on a regional scale. The discussion of the Birdhead Sandstone is vague and the mapping is somewhat incomplete. Thom *et al*. were the first to name the Birdhead Sandstone. This name was given because of the exposure in Birdhead Coulee immediately northwest of the thesis area.

Knappen and Moulton (34) mapped a large area to the west of the thesis area and adjacent to the area mapped by Thom et al. This report only made reference to a sandstone near the middle of the Thermopolis Shale and correlated it to the Muddy Sandstone of Wyoming. The authors did describe channeling of this sandstone (here called the Birdhead) into the shale below and suggested a fluvial origin.

The structure of the Pryor Mountains was mapped by Blackstone (4). His map included T. 5 S., Rs. 27 and 28 E., of the thesis area. He delineated the general structure of Shively Hill Dome, North Pryor Mountain, and Castle Butte Fault which all lie within the thesis area. Blackstone's map was general in nature and was concerned mainly with the faulting and folding rather than stratigraphy.

Wulf (72), in a discussion of the Lower Cretaceous stratigraphy of the northern plains, briefly described the Birdhead Sandstone. He designated the exposure in Birdhead Coulee in the NW 1/4 sec. 9, T. 3 S., R. 27 E., Yellowstone County, Montana, as a more specific type locality of the Birdhead Sandstone. Wulf's report does not include a geologic map.

Drainage

All streams and rivers in and around the area studied eventually flow into the Yellowstone River which lies to the north (Index Map, Plate 3). The perennial and intermittent streams in the western half of the area flow into Pryor Creek. Those in the eastern half empty into Beauvais Creek, a tributary of the Big Horn River, which in turn joins the Yellowstone River at Hardin, Montana. Woody Divide is the separation between these two drainage systems.

Deep Creek, Hay Creek, and East Fork of Pryor Creek compose the major north-flowing perennial drainage on the western side of Woody Divide, and Beauvais Creek forms the perennial drainage on the eastern side. The North Fork of Woody Creek flows north down the center of Woody Divide.

Climate

A permanent U. S. Weather Bureau station is located at Billings, Montana. A station nearer to the area is located at Pryor, Montana, but reports only precipitation.

The average temperature in the vicinity of the mapped area is approximately 45° F. The coldest month of the year is usually December with the average temperature about 15° F. Lows of -25°F have been recorded during December. July and August are the hottest months having an average temperature of about 75°F. Temperatures of over 100°F have been recorded for these months.

The average precipitation for the area is approximately 24 inches. Most of the rainfall occurs during April. July is the month with the least amount of precipitation. The rainfall usually occurs as afternoon thunderstorms during the summer months. The precipitation during the winter months is in the form of snow which is generally not deep except at higher elevations.

Vegetation

Several types of vegetation cover the mapped area. There is a direct correlation between rock type and vegetation type. Except for a few heavily vegetated stream valleys near North Pryor Mountain, the vegetative cover does not hinder geologic field work.

In the lower stream valleys cottonwood, willow and boxelder trees stand in groves. The flat north-sloping plains are usually covered by short grasses, sage brush, and prickly pear cactus. The higher parts of the area on North Pryor Mountain and on Shively Hill Dome support a thin cover of short grasses, scrub oak, and pines.

The flat plains area and Woody Divide have primarily shale soils and produce the short grasses and sagebrush. The upper areas of Shively Hill Dome and North Pryor Mountain have soils formed from sandstones or limestones and support mainly sparse grasses, scrub oaks, and pines. The Tensleep Sandstone can generally be mapped by the presence of pines as opposed to the short grasses found on adjacent formations.

Wheat and barley are raised by dry farming on the lower flat plains. Hay and alfalfa are raised by irrigation on some of the bottom lands of the creeks.

Quality and Extent of Exposures

The quality of outcrop exposures within the thesis area is on the whole excellent. Deep dissection of the structures in the southern part of the area expose Mississippian to Jurassic formations. Stream cuts and coulees exposes the Cretaceous formations throughout the remainder of the area.

Only at the foot of North Pryor Mountain and at the south and east ends of Woody Divide, are the outcrops covered by talus or slumping. Even in these areas of cover, the general outcrop trend is evident.

STRATIGRAPHY

The thesis area is located in a region between the northern parts of the Powder River Basin and the Big Horn Basin. The formations in the mapped area appear to be more closely related to the units in the Big Horn Basin in history and source. The rocks north of the area were deposited in the Central Montana Trough and generally differ in some respects from the rocks in the thesis area which were deposited on the northern edge of the Wyoming Shelf.

Thesis Area Stratigraphy

The rocks in the area range in age from Mississippian to Early Cretaceous. Pre-Mississippian rocks are exposed south of the area in the Pryor and Big Horn Mountains. Rocks of Late Cretaceous to Late Tertiary age have been stripped from the area by erosion but are found in areas to the north and east.

Subsurface Stratigraphy

The oldest formation which crops out in the thesis area is Mississippian in age. Because there are no wells within the mapped area, all knowledge of the subsurface rocks must be inferred from outcrops or from well data in adjacent areas. Several sections of pre-Mississippian rocks have been described in the Northern Pryor

Mountains to the south. A single well to the northeast of the area provides usable information about the subsurface rocks.

From the information available in the literature, a probable subsurface stratigraphic column was synthesized. The formation names used in the following discussion are those which best describe the type of rocks assumed to be present in the subsurface of the thesis area.

Precambrian

Crystalline rocks of Precambrian age were reported by Thom et al. (63) from the northern Big Horn Mountains near Point Lookout in Big Horn County, Montana, and from the core area of the Big Horn Mountains of Wyoming. They described the rocks of the Northern Big Horn Mountains as gray and red granites, and the Precambrian rocks in the Wyoming segment of the Big Horn Mountains as granites intruded by dikes of diabase, olivine gabbro, hornblende diorite, and peridotite. These granites are found mainly at the north and south ends of the range. Doroshenko (21) reported that a belt of older gneisses with amphibolites and schists is present in the central Big Horn Mountains of Wyoming. It is assumed that crystalline rocks similar to those described by Thom et al. and Doroshenko form the basement complex of the thesis area.

Cambrian

Darton (17) reported that nearly 900 feet of Cambrian rocks rest nonconformably on the Precambrian basement in the northern Big Horn Mountains of Montana. He grouped these rocks into the Deadwood Formation. A sequence of Cambrian rocks was described by Shaw (60) from his East Pryor Mountain section located in sec. 36, T. 7 S., R. 28 E., Carbon County, Montana. This measured section, nearly 800 feet thick, lies directly south of the thesis area and is probably representative of the subsurface Cambrian section of the mapped area. Shaw divided the rocks into three formations. He called the basal coarse quartzose sandstone the Flathead Formation. The overlying unit he named the Gros Ventre Formation. This formation consists mainly of clastic argillaceous material with the upper part containing thin-bedded limestones and a flat-pebble conglomerate. This unit is a correlative of the Gros Ventre and Gallatin Groups of southwestern Montana. The Meagher and Du Noir Limestones which are present at Cooke City, Montana, are absent in the Pryor Mountains and therefore the shale units are not clearly divided as they are at Cooke City. It is for this reason that the term "formation" has been substituted for group. Capping the Gros Ventre Formation is a unit Shaw termed the "Grove Creek Limestone." This name is not entirely suitable because it was originally used as a time-rock unit, but for lack of a proper substitute it is used here in a lithic sense. This youngest Cambrian formation is composed of green to gray-green, flat-pebble conglomerate with thinner limestones. Interbedded with the limestones are green and gray-green arenaceous and calcareous shales.

Ordovician

Thom _et al_. (63) found Ordovician rocks exposed at the north end of the Pryor Gap in the northern Pryor Mountains. They described the rocks as massive dolomites and thin-bedded limestones belonging to the Big Horn Dolomite. Shaw (60) found that the upper part of the "Grove Creek Limestone" contained Early Ordovician fossils at his East Pryor Mountain section. He reported Late Ordovician fauna in the Big Horn Dolomite which rests disconformably on the "Grove Creek Limestone."

Shaw described the Big Horn Dolomite as consisting of two members. The lower member is a massive dolomite which is light gray to buff or tan and is characterized by rough, knobby weathering surfaces. The upper member is called the Leigh Member and consists of light-colored, thin-bedded dolomites and limestones. Shaw measured approximately 400 feet of Ordovician rocks. Since Shaw's section lies immediately south of the thesis area, it is assumed that a similar sequence of Ordovician rocks is present at depth in the mapped area.

Silurian

The presence of Silurian rocks in the subsurface of the area is questioned. No outcrops of Silurian rocks are reported from the Big Horn or Pryor Mountains. It is possible that a thin sequence of Silurian rocks was penetrated in the Stanolind Crow Tribal No. 1 in the C NW1/4 NE1/4, sec. 30, T. 3 S., R. 30 E., Big Horn County, Montana, located northeast of the thesis area. Wells drilled to the north and west of the thesis area do not encounter Silurian rocks.

Since the well data is inconclusive and no outcrop data is available, it is assumed that Silurian rocks are not present in the subsurface of the thesis area. Silurian rocks similar to those found in the Williston Basin were probably removed by erosion from south-central Montana during Late Silurian or Early Devonian time.

Devonian

Devonian rocks were not recognized by Thom *et al*. (63) or by Blackstone (4) in the Pryor Mountains. However, after several years of intermittent field investigations, Blackstone and McGrew (5) reported a Devonian section in a canyon of Little Dryhead Creek, sec. 23, T. 7 S., R. 27 E., Carbon County, Montana. This section is immediately south of the thesis area. Sandberg (58, 59) confirmed the exposures in the Little Dryhead Creek canyon and found an additional exposure in Pryor Gap. Also the Stanolind Crow Tribal No. 1, cut nearly 200 feet of Devonian rocks. Because of the information obtained from the sections exposed in the Pryor Mountains to the south and from the well to the northeast, it is assumed that between 200 and 400 feet of Devonian rocks are present in the subsurface of the thesis area.

The Early Devonian Beartooth Butte Formation may not be present in the thesis area subsurface. Where present this formation lies unconformably on the Leigh Member of the Ordovician Big Horn Dolomite and consists of red siltstones and limestones or dolomite conglomerates. The Jefferson Limestone disconformably overlies either the Beartooth Butte Formation or Ordovician rocks. The Jefferson Limestone consists of brown to buff, finely crystalline, massive dolomites and limestones. The upper part of the Devonian section consists of the Three Forks Formation. Platy dolomites and limestones, containing "free floating" rounded, frosted sand grains, and intercalated greenish siltstones and shales characterize the Three Forks Formation. The Mississippian Madison Limestone rests disconformably on the Upper Devonian Three Forks Formation in other areas, but this contact is not exposed within the thesis area.

Surface Stratigraphy

Madison Limestone

The oldest formation exposed in the mapped area is the Madison Limestone, which is Mississippian in age (Table 1). This thick sequence of limestone was named by Peale (47) in the Madison Range near the central part of the Three Forks Quadrangle, Montana. He subdivided the sequence into the lower laminated limestones, the middle massive limestones and the upper jaspery limestones. The Madison has since been divided by Collier and Cathcart (12) into two distinct formations, and the Madison has been given a group designation. Because of the poor quality and limited extent of exposures of the Madison within the thesis area, it was not divided into the Mission Canyon and Lodgepole Formations. Therefore, in the following discussion, this sequence will be referred to as the Madison Limestone and will be treated as a single unit.

The base of the Madison Limestone is not exposed in the thesis area, Denson and Morrisey (20) have described the basal contact of the Madison in the Big Horn Basin as a marked unconformity which truncates beds ranging in age from Cambrian to Devonian. Since rocks of Devonian age were found by Sandberg (58 and 59) and Blackstone and McGrew (5) in Little Dryhead Creek

Table 1. Correlation Chart

System	Series	Northern Big Horn Basin	Thesis Area	Crazy Mountain Basin	Northern Powder River Basin
CRETACEOUS	Lower	Mowry Sh.	Mowry Sh.	Mowry Sh.	Mowry Sh.
		Thermopolis Sh.	Thermopolis Sh.: Upper Mbr	Thermopolis Sh.	
		Muddy Ss.	Birdhead Ss.	Muddy Ss.	Newcastle Ss.
		"Dakota Silt"	Lower Mbr		Skull Creek Sh.; "Dakota Silt"
		Cloverly Gr.: Fall River Ss.	Cloverly Gr.: "Rusty Beds"	Fall River Ss.	Inyan Kara Gr.: Fall River Ss.
		Fuson Sh.	Fuson Sh.	Kootenai Fm.	Fuson Sh.
		Lakota Ss.	Pryor Cgl.	Basal Cgl.	Lakota Ss.
JURASSIC	Upper	Morrison Fm.	Morrison Fm.	Morrison Fm.	Morrison Fm.
		Sundance Fm.: Upper Mbr	Sundance Fm.	Ellis Gr.: Swift Fm.	Ellis Gr.: Swift Fm.
		Lower Mbr		Rierdon Fm.	Rierdon Fm.
	Middle	Gypsum Springs Fm.		Piper Fm.	Piper Fm.
	Lower?				
TRIASSIC		Chugwater Fm.	Chugwater Fm.	Chugwater Fm.	Chugwater Fm.
		Dinwoody Fm.		Dinwoody Fm.	Goose Egg Fm.; Spearfish Fm.; Minnekahta Fm.
PERMIAN		Phosphoria Fm.	? Embar Ls.	Phosphoria Fm.	Opeche Sh.
PENN.		Tensleep Ss.	Tensleep Ss.	Tensleep Ss.	Tensleep Ss.; Minnelusa Fm.
		Amsden Fm.	Amsden Fm.	Amsden Fm.	Amsden Fm.
MISS.		?	?	Alaska Bench Fm.; Tyler; Big Snowy	?; Charles
		Madison Ls.	Madison Ls.	Madison Ls.	Madison Ls.

Compiled from various sources by G.R. George canyon seven miles south of the thesis area, it is assumed that the Madison Limestone lies unconformably upon the Devonian Three Forks Formation within the mapped area. The upper contact of the Madison is placed at an erosional unconformity which is best seen in the canyon cut by East Fork Pryor Creek in Shively Hill Dome. The upper part of the Madison shows collapse or solution features (Figure 3) overlain by a red, clayey shale containing angular chert fragments. The red shale and the collapse features represent an erosional surface and a regolith. Overlying the unconformity are undisturbed beds of the Amsden Formation.

Distribution and Topographic Expression. The Madison Limestone is widely exposed throughout the northern Rocky Mountain region. It generally forms prominent cliffs and canyons. In the Big Horn Mountains and the Pryor Mountains of Montana and Wyoming, it forms most of the surfaces of the higher uplifted areas and is usually well-exposed where the terrain is deeply dissected. Within the mapped area, the Madison Limestone is exposed on North Pryor Mountain where it forms the major dip slopes of the flanks. The upper part of the Madison is seen in the bottom of the canyon cut by East Fork Pryor Creek in Shively Hill Dome. The Madison generally forms a prominent cliff or ledge where it is nearly horizontal. Where folded, the formation forms long smooth dip slopes such as those on the northeast flank of North Pryor Mountain.

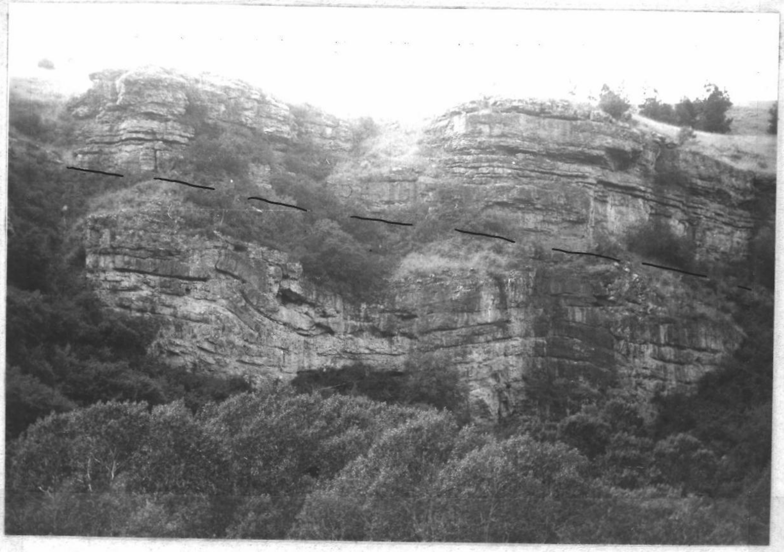


FIGURE 3. Collapse or solution features in the Madison Limestone unconformably overlain by the basal limestone of the Amsden Formation.

Lithology and Thickness. The Madison Limestone consists of a thick sequence of various types of limestones and dolomites. Most of the limestones are light-colored, ranging from medium gray through tan to nearly white. All units generally become lighter in color when weathered. Crystalline limestones which appear to be partially dolomitic in the hand specimen are common. In the lower part microcrystalline micritic limestones occur. Generally in the lower part and also in the uppermost part of the section, chert in the form of nodules and stringers is present. Much of the Madison is fossiliferous and many units are skeletal limestones.

A red brecciated zone in the upper Madison was found in the section measured on North Pryor Mountain. This red, cherty limestone breccia may represent a local erosional surface within the upper Madison or, according to Andrichuk (3), it may be a solution breccia with an anhydrite component removed.

The Madison Limestone is characterized by thick limestone beds. There are interbedded thinner limestones and dolomites present, but these usually are not well-exposed because they are slope-formers between cliffs of the thicker units.

Because a complete section of Madison Limestone is not exposed in the mapped area, the thickness is unknown. A Madison section exposed in a deep canyon on the northeast flank of North

Pryor Mountain is nearly 800 feet thick. However, the upper contact is obscured and the base is not exposed. Thom *et al.* (63) measured about 1,000 feet of Madison elsewhere in the Pryor Mountains.

Age. The Madison Limestone is generally fossiliferous. Brachiopods, corals, and crinoids are common. Weller *et al.* (67) reported Late Kinderhookian fossils in the lower part of the Madison and believed that the entire formation is Late Kinderhookian to Osagian in age, a dating based on the brachiopod, *Spirifer centronatus.* A variety of fossils were collected by Thom *et al.* (63) and were identified by G. H. Girty. The fossils were mainly found in the upper and lower parts of the Madison in the Pryor Mountains and Big Horn Canyon and were considered entirely Mississippian by the authors.

Source Rocks and Depositional Environments. According to Sloss (61), the thesis area would have been in a zone located near the Wyoming Shelf to the south during the Mississippian. The general absence of terrigenous clastic material in the Madison Limestone indicates that it was deposited in a relatively stable, outer shelf zone. The type of fauna present in the lower beds (brachiopods, horn corals, and crinoids) generally represents shallow, normal marine waters in a relatively high energy zone. Evaporite sequences of dolomite, anhydrite, and halite are reported by Andrichuk (3) to characterize part of the upper Madison in parts of Montana. However, no anhydrite or halite units were found in the Madison exposed on North Pryor Mountain. The rocks examined within the thesis area indicate that the majority of the carbonates of the upper Madison were deposited in shallow, normal marine waters and that the source of the carbonate was primarily organic rather than chemical precipitation.

Amsden Formation

The Amsden was first named by Darton (16) for exposures of red shales, limestones, sandstones, and cherty beds on the Amsden Branch of the Tongue River west of Dayton, Wyoming. The Amsden Formation is separated from the Madison Limestone below by a regional erosional unconformity. Within the thesis area this unconformable contact is best exposed in East Fork Pryor Creek canyon at Shively Hill Dome. The collapse features found in the upper Madison indicate extensive solution and erosion prior to deposition of the Amsden. The upper contact of the Amsden is difficult to locate within the mapped area. It is arbitrarily placed at the base of a quartzose sandstone which is considered to be the base of the Tensleep Sandstone. The contact between the Amsden

Formation and the overlying Tensleep Sandstone, apparently gradational in the thesis area, becomes an erosional contact in areas north and west where the Amsden is partly or entirely absent.

Distribution and Topographic Expression. The Amsden Formation is exposed throughout south-central Montana and in the northern Big Horn Basin west of the thesis area. In southwestern Montana the Amsden is often missing, having been removed by erosion. East of the thesis area the Amsden is found in the Big Horn Mountains and on the western side of the Powder River Basin. On the eastern edge of the Powder River Basin the Amsden passes into the lower part of the Minnelusa Formation (Table 1).

Within the mapped area, the Amsden Formation crops out on the east flank of North Pryor Mountain but it is best exposed in the East Fork Pryor Creek canyon cut in Shively Hill Dome. In the canyon the lower part of the Amsden forms a small cliff and is relatively resistant to erosion. The upper part is composed of thin sandstones and limestones interbedded with nonresistant shales which generally form covered slopes (Figure 4). On North Pryor Mountain the Amsden outcrop is usually covered by limestone talus from the Madison Limestone which crops out up slope. The upper part of the Amsden on North Pryor Mountain is represented only by a few thin limestones and a red soil cover.

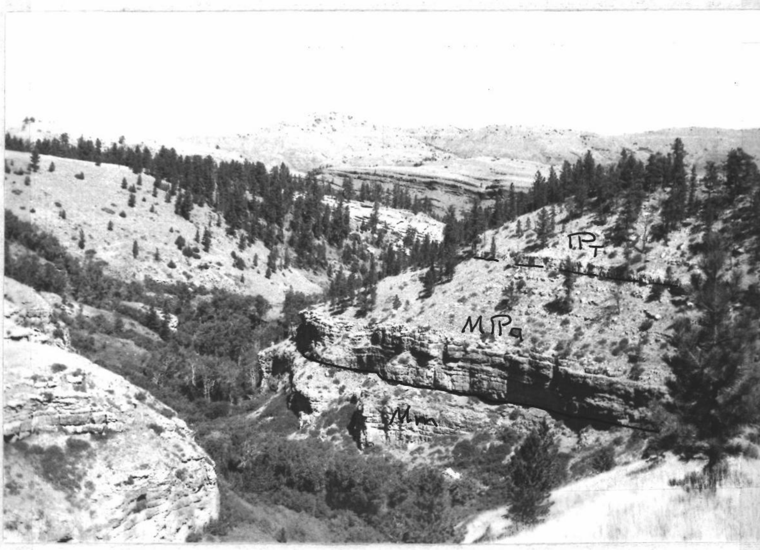


FIGURE 4. Canyon on East Fork of Pryor Creek. The lower Amsden Formation (MIPa) forms a cliff above the Madison Limestone (Mm); the upper part forms a slope below the Tensleep Sandstone (IPt).

Lithology and Thickness. The Amsden Formation is characteristically composed of several lithologies. Red shales and siltstones and purple limestones are the most characteristic features of this formation. No single unit can be traced laterally for any great distance nor can any particular unit be correlated to any regional extent.

The Amsden section measured in East Fork of Pryor Creek canyon was divided into four units. The basal unit is a five-foot, red, clayey shale containing angular chert fragments. This shale probably represents a regolith accumulated on the eroded Madison Limestone. For mapping purposes the basal red shale was arbitrarily placed within the Amsden Formation rather than the Madison Limestone.

The second unit consists of 50 feet of limestone. The lower 35 feet is fine- to medium-crystalline and cherty. It is brown to gray and weathers to light brown. The chert occurs mainly in nodules which are elongated parallel to the wavy bedding planes. The chert is yellow-brown, red, or gray in color. Fifteen feet below the top of the second unit a seven-foot, cherty, limestone breccia is present. Overlying the limestone breccia is an even-bedded, red-stained limestone, eight feet thick, which contains thin red shale partings.

A sequence of thin, locally cherty limestones, ranging in color from purple to brown and white, interbedded with red shales and thin sandstones composes the third unit. This sequence is about 50 feet thick. The sandstones of this unit are very fine- to medium-grained and consist mainly of subrounded quartz grains. They are well-bedded and generally are about three to six feet thick.

The upper or fourth unit is a sequence of white quartzose sandstones with a six-foot brown limestone at the top. This uppermost unit is about 30 feet thick. In the upper part, float from a covered zone 12 feet thick indicates the presence of brown shale with sandstone. This fourth unit is the transitional zone between the Amsden and the overlying Tensleep Sandstone. The upper contact of the Amsden is arbitrarily placed at the base of a thick sequence of clean, white to tan, cross-bedded, quartzose sandstones which overlie the six-foot brown limestone at the top of the fourth unit. The sequence of cross-bedded sandstones above the fourth Amsden unit is considered to be the basal part of the Tensleep Sandstone.

Gardner _et al_. (24) measured 135 feet of Amsden Formation six miles west of the thesis area. Thom _et al_.(63) reported between 156 and 365 feet of Amsden in the Crow Indian Reservation and showed the thickest section to be located in the Big Horn Canyon east of the thesis area. The section measured by the writer in East Fork Pryor Creek canyon is about 140 feet thick.

Age. When Darton (16) originally defined the Amsden Formation in the Big Horn Mountains, he assigned a Late Mississippian age to the lower part and an Early Pennsylvanian age to the upper part. Since Darton's original definition, the boundary between the Mississippian and the Pennsylvanian has been the topic of much discussion. Thom *et al.* (63) considered the Amsden to be entirely Pennsylvanian in age in the Crow Indian Reservation, but did not present evidence supporting their conclusions. Sloss (24) reported definite faunal evidence that the basal Amsden is Late Mississippian in age. Williams (69, 70), Wilson (71), Branson (7), and Henbest (29) all presented summaries of the boundary problem in relation to the Amsden. This group of authors generally felt that the lower part of the Amsden is Mississippian in age. Wilson (71) and Williams (70) pointed out that the Amsden transgresses this boundary in its widespread distribution. Henbest (23) and Agatston (1) reported Pennsylvanian fusulinids in the upper units of the Amsden in southern Montana. There seems to be no question that in any complete section of Amsden the upper part is definitely Pennsylvanian in age. However, the problem of assigning a definite age to the lower part of the Amsden Formation is still unresolved.

Within the thesis area no fossils were found in the Amsden Formation by the writer. The measured section in East Fork Pryor Creek canyon appears to be complete because of the absence of intraformational unconformities and the nature of the upper transitional contact. Therefore, the upper Amsden is believed to be Pennsylvanian in age. The age of the lower part of the Amsden within the thesis area is uncertain, but it is designated as Late Mississippian because published information supports such a conclusion.

Source Rocks and Depositional Environment. The limestones of the lower Amsden Formation contain marine fossils, mainly brachiopods (Sloss 24), at several localities. The upper part of the Amsden has been reported by Henbest (28) and Agatston (1) to contain fusulinids. This faunal evidence indicates a shallow marine environment for much of the Amsden strata. The abrupt changes in lithologies in the upper Amsden also suggest shallow water. The sandstones in the upper Amsden are generally well-sorted, structureless, and are composed of subrounded to subangular, medium-grained quartz. The absence of unstable material in the sandstones and their well-sorted nature indicate long transport with progressive sorting, recycling, or a high energy environment such as a beach or bar. Wilson (71) suggests that the Amsden carbonates were deposited in a shallow, quiet offshore area. He states that a low positive area to the south provided some clastic material but that the red shales and sandstones may have been derived from erosion of the Madison. Either the source of clastic material was low and far removed from the site of deposition, or the material was thoroughly reworked in a beach or bar environment.

Tensleep Sandstone

Darton (16) in 1904 gave the name Tensleep Sandstone to the light-colored, cross-bedded sandstone exposed in the lower canyon of Tensleep Creek in the Big Horn Mountains, Wyoming. This sandstone lies between the older Amsden Formation and the younger Embar Limestone. Within the mapped area the interbedded limestones, sandstones, and shales of the upper Amsden grade upward into a sequence of quartzose sandstones assigned to the Tensleep. The basal contact of the Tensleep is arbitrarily placed at the base of a sandstone which is the bottom unit in a continuous sequence of cross-bedded, quartzose sandstones. The Embar Limestone in the mapped area appears to lie conformably upon the Tensleep Sandstone. However, because of the change in lithology from quartzose sandstone to cherty limestone and the local silicification found in the upper Tensleep, the upper contact may represent a disconformity. Williams (70) and Agatston (1) both reported that the Tensleep Sandstone thins from Wyoming north into southern Montana as a product of post-Tensleep erosion. Verville (65) found possible Wolfcampian fusulinids at the top of the Tensleep in the southern Big Horn Mountains but found only Desmoinesian fusulinids in the

Tensleep of the western and northwestern Big Horns. He also noted thinning of the unit to the north. The absence of either Late Pennsylvanian or Permian fusulinids and the trend of thinning to the north indicate that the upper contact of the Tensleep Sandstone in south-central Montana is a disconformity.

Distribution and Topographic Expression. The Tensleep Sandstone occurs widely throughout northern Wyoming and southern Montana. It is correlated with the Quadrant Quartzite to the southwest in Montana and the Wells Sandstone of western Montana and southeastern Idaho. The Tensleep is correlative to the upper part of the Minnelusa Formation in the Powder River Basin (Table 1).

The Tensleep Sandstone in the thesis area is limited to exposures in the southern part. It is well-exposed in East Fork Pryor Creek canyon on the east side of Shively Hill Dome and also in a small canyon cut by Hay Creek between Shively Hill Dome and North Pryor Mountain. The upper part of the Tensleep is exposed over the central area of Shively Hill Dome, especially on the western flank. On the east flank of North Pryor Mountain the Tensleep Sandstone forms flatirons with dips as high as 40°. The contacts of the exposures on North Pryor Mountain are generally covered by talus from the Madison and Amsden formations which crop out up slope. The Tensleep is also exposed by erosion and faulting in secs. 32 and 33, T. 5 S., R. 28 E. of the mapped area.

The Tensleep Sandstone is a relatively resistant unit. It forms steep-walled coulees such as those cut by Hay Creek and its tributaries on the west flank of Shively Hill Dome (Figure 5). On the north side of the dome it forms small ridges and scarps (Figure 6). It is of interest that on the dome the Tensleep can be mapped on the basis of pine tree cover. The Embar Limestone which covers most of the inner dome surface is grass-covered whereas pines grow on the Tensleep because of the water carried by this porous sandstone.

Lithology and Thickness. The Tensleep Sandstone is composed of cross-bedded quartzose sandstone in the thesis area. Darton (16) first described the Tensleep as a light-colored, cross-bedded, quartzose sandstone. His general description readily fits the Tensleep found in the mapped area.

In a small canyon carved by Hay Creek on the northwest side of Shively Hill Dome, the Tensleep consists of three main units. The basal unit is relatively thin-bedded sandstone. The beds are one to five feet thick, platy, and are invariably cross-bedded. These lower beds are composed of fine- to medium-grained, subangular to angular quartz. Some beds appear to contain minor amounts of clay while others are well-sorted and clean. The middle unit is a 30 to 40 feet thick zone which is cross-bedded on a large scale. Trough cross-bedded sets are up to 10 feet thick. The sandstones

FIGURE 5. The canyon wall is formed in the upper Tensleep Sandstone. In the background the Amsden Formation and Tensleep form flatirons on the eastern flank of North Pryor Mountain.

FIGURE 6. Upper Tensleep Sandstone on Shively Hill Dome showing planar cross-bedding. Note the pine trees preferentially growing on the Tensleep down the coulee.

of the middle zone consist of medium-grained, subangular quartz with local coarse-grained zones. There are very few impurities in this generally well-sorted unit. However, these beds are carbonate-cemented and are more resistant than the basal unit. The beds in the upper 30 feet of the Tensleep Sandstone are more thinly bedded than those of the middle zone. The lower part of the upper division consists of beds three to five feet thick while the uppermost beds range from one to four feetin thickness. All beds are planar cross-bedded except for the uppermost beds which are even-bedded. The upper unit is tan to light gray and composed of well-sorted, fine- to medium-grained subangular quarts which is frosted. This upper unit is very calcareous at some localities, but is friable at the surface because of leaching of the carbonate cement. Locally, as on the west side of Shively Hill Dome, large blocks of Tensleep Sandstone, up to 10 feet in diameter, weather out of the upper part. These blocks are extremely well-cemented with quartz and are very resistant to weathering.

The Tensleep Sandstone is characteristically cross-bedded. Measurements of the dip directions of the cross-beds on Shively Hill Dome indicate current flow directions ranging from southeast to southwest. Agatston (1), however, found that on a regional basis no prevailing current direction could be determined from the cross-bedding in the Tensleep. He did find a slight overall southerly trend on a statistical basis.

A complete section of Tensleep Sandstone showing both contacts was not found within the thesis area. The 100-foot section measured on Hay Creek is well-exposed but the basal contact is covered. Gardner et al. (24) measured 153 feet of Tensleep in a section about six miles southwest of the thesis area. Thom et al. (63) reported only 45 to 75 feet within the Crow Indian Reservation. Since no complete section can be measured within the thesis area, the thickness of the Tensleep is unknown. It is assumed that the Tensleep Standstone is slightly more than 100 feet thick within the mapped area.

Age. Fossils were not found by the writer in the Tensleep Sandstone. However, a varied fauna has been found in southwestern Montana and northern and northwestern Wyoming. Henbest (28) reported fusulinids in the upper Tensleep near Big Horn Canyon ten miles east of the thesis area. He found the Fusulina-Wedekindella zone which is Desmoinesian in age. In Wyoming Agatston (1), Henbest (29), Branson (7), and Williams (70) all recognized faunas from the Tensleep ranging from Atokan to Desmoinesian in age. Gardner et al. (24) designated the Tensleep as being Desmoinesian in age in south-central Montana. The faunas have been found at most stratigraphic intervals within the formation. Based on these data from other areas, the Tensleep Sandstone within the thesis area is considered Desmoinesian and possibly Atokan in age. If the upper Tensleep is assumed to be Desmoinesian in age and the overlying Embar Limestone is entirely Permian, there is additional evidence for a disconformable upper contact.

Source Rocks and Depositional Environment. The cross-bedding in the Tensleep Sandstone shows no prevailing current flow direction and therefore no definite source direction can be suggested on this basis. Quartz is the dominant detrital mineral in the Tensleep. The heavy minerals include tourmaline, zircon, magnetite, and ilmenite, with a few grains of staurolite. The absence of any unstable detrital components indicates that the Tensleep may have been derived from pre-existing sandstones. Because the quartz grains are generally subangular, it must also be considered that the well-sorted nature of the Tensleep may be a product of long transportation or thorough reworking in a specific environment.

Agatston (1) suggested a source west or south of Wyoming because of regional thinning to the east in Wyoming and the limestone facies to the east. Branson (7) stated that the sand for the Tensleep was derived from older sandstones but did not suggest their age or location. Sloss (61) suggested a source in western Idaho based on regional stratigraphy. At present no definite source area for the Tensleep Sandstone can be proved.

The faunas in the Tensleep in Wyoming and Montana are marine in nature and indicate a stable shelf condition. Branson (7) stated that the upper part of the Tensleep was deposited in shallow marine water. Williams (70) suggested a marine environment for the entire formation. Agatston (1) reported that the fusulinids and brachiopods found in the Tensleep represent a shallow marine environment. He also proposed that sands being carried into the site of deposition of the Tensleep were frosted by wind action.

The dominance of quartz and the presence of an impoverished heavy mineral suite indicate a high energy environment involving possible reworking and constant sorting. Also, because of the large-scale cross-bedding and the well-sorted nature of the Tensleep Sandstone, it is possible that the environments of deposition were beach, offshore bar, and coastal dune.

Embar Limestone

In the thesis area a thin brown to tan cherty limestone lies between the Triassic Chugwater Formation and the Pennsylvanian Tensleep Sandstone. This sequence of rocks is the Embar Limestone. Darton (18) first used the name Embar to describe a sequence of thin-bedded, pyritic dolomites and limestones with subordinate green shales found in the Owl Creek Mountains of Wyoming. He later stated (17) that the sequence was named for the Embar

Post Office on Owl Creek. Condit (13), in western Wyoming, divided the Embar into the Permian Park City Formation and the Triassic Dinwoody Formation on the basis of lithology. Richards and Mansfield (56) substituted the name "Phosphoria" for the Park City in northwestern Wyoming. Thomas (64) in 1934 found that in the Owl Creek Mountains and in central Wyoming the Phosphoria and Dinwoody Formations interfinger to the southeast with red beds. He gave the name "Embar Formation" to the unit consisting of red beds and intercalated marine limestone and sandstone tongues which lies between the Tensleep Sandstone below and the Chugwater Formation above. This usage has been accepted for central Wyoming, the northeastern side of the Big Horn Basin, and the Pryor Mountains. Within the thesis area, the Embar is dominantly limestone and therefore is called the Embar Limestone after Knappen and Moulton (34) and Thom *et al*. (63).

The Embar Limestone concordantly overlies the Tensleep Sandstone. The nature of this contact is uncertain. The question of whether the contact represents a disconformity or a continuous sequence was discussed in the previous section on the Tensleep Sandstone. A study of insoluble residues from the basal limestone of the Embar shows that a high percent of quartz sand and some argillaceous material are present. The quartz is generally finer-grained than that of the Tensleep Sandstone, but is subangular, well-sorted, and frosted in the same manner as the Tensleep. Heavy minerals found cannot be differentiated from those found in the upper Tensleep. It is not clear whether the quartz grains in the basal Embar represent a reworking of the Tensleep sandstones or whether they were derived from the same source.

The upper contact of the Embar is not clearly exposed in the mapped area. However, the Embar Limestone maintains a relatively constant thickness throughout the area and at least locally appears to be conformably overlain by the Triassic Chugwater Formation.

Distribution and Topographic Expression. The Embar Limestone is found in the Owl Creek, Big Horn, and Pryor Mountains of Wyoming and Montana. It is represented by a thin limestone sequence in the Pryor Mountains. Within the mapped area the central area of Shively Hill Dome is covered by the Embar, and several dip slopes on the dome are capped by this formation. The central area of the synclinal valley between Shively Hill Dome and North Pryor Mountain is covered by the Embar Limestone and associated red soils from the overlying Chugwater Formation. In the southeastern part of the thesis area, the Embar covers the floor of the valley in secs. 29, 32, 33, T. 5 S., R. 28 E. Several small canyons have been cut into the Embar by the headwaters of Beauvais Creek in this area. The contact between the Tensleep Sandstone and the Embar is well-exposed in a few of the canyons.

The relatively resistant Embar Limestone generally forms a smooth, grass-covered or talus-littered dip slope or valley floor where it is exposed in the thesis area. Where cut by stream erosion, a small coulee or valley is rapidly formed in the underlying Tensleep Sandstone.

Lithology and Thickness. The Embar Limestone in the thesis area is mainly brown to tan cherty limestone. In a section measured in sec. 32, T. 5 S., R. 28 E., the basal unit of the Embar is a three-foot thick, reddish brown, finely crystalline, quartzose, limestone. Insoluble residues from this unit contain subrounded, frosted, fine-grained quartz in abundance with a minor amount of medium-grained, rounded quartz. Locally the basal unit contains very little quartz and is slightly vuggy with calcite veins. The overlying bed is either a highly quartzose limestone or a calcareous quartz arenite. It is nearly two feet thick, light tan to brown in color, and is locally soft or nonresistant. Above this sandy bed is a very cherty limestone which is about nine feet thick. The chert contained is buff to tan and occurs in nodules and horizontal stringers. A three-foot, orange to red-brown, quartzose limestone overlies the cherty bed. It is well-cemented, dense, and contains a large amount of quartz sand and silt. It is this unit which supports dip slopes formed on the Embar. The top unit is a two-foot, hard brown limestone which is locally cherty and commonly fractured.

The measured section in sec. 32, T. 5 S., R. 28 E., is nearly 20 feet thick. The Embar measured on Hay Creek is closer to 25 feet in thickness. It is assumed that this unit is of nearly constant thickness in the thesis area. To the west of the area, Knappen and Moulton (34) report only 10 to 15 feet of Embar. Blackstone (4) found that the Embar of the Pryor Mountains thickens to the south. The Embar is not found north of the Yellowstone River.

Age. The age of the Embar in the thesis area is unknown. No fossils have been found in this formation in the Pryor Mountains region. Gardner *et al*. (24) stated, without reference to localities, that the Embar contains Permian marine invertebrates. Darton (18) reported Permian brachiopods present in the Embar in Big Horn River canyon south of Thermopolis, Wyoming. This formation has been designated as Permian primarily on the assumption that it can be correlated to the Embar Formation as described by Darton (18) and by Thomas (64). If it is correlative to the Embar of Wyoming on the basis of stratigraphic position alone, it may not everywhere be of the same age. The Embar Limestone exposed in the thesis area is assumed to be Permian in age only on the basis that formations in approximately the same stratigraphic position in adjacent areas to the south and southeast contain Permian faunas.

Source Rocks and Environment of Depostion. The limestone beds of the Embar contain considerable amounts of quartz sand.

The source of this sand is not known, but it may have been similar to that of the Tensleep Sandstone. The heavy mineral suite is quite impoverished and could not be readily distinguished from the heavy mineral suite of the Tensleep.

Gardner et al. (24) stated that marine invertebrates are found in the Embar but give no localities or fossil types. Darton (18) reported marine brachiopods from the Embar in Wyoming. The limestones in the interfingering Embar sequence as described by Thomas (64) are considered marine. Knappen and Moulton (34), however, described the Embar Limestone west of the thesis area as having the appearance of a chemical precipitate.

Further investigation for fossils and additional detailed mapping and correlation are necessary to establish source rocks and environment of deposition. It is suggested that the Embar Limestone in the thesis area is marine in origin simply on the basis that elsewhere marine fossils are present.

Chugwater Formation

A thick sequence of red beds found near Chugwater Creek in the vicinity of Iron Mountain in Wyoming was named the Chugwater Formation by N. H. Darton (16) in 1904. This sequence of red beds, thought to be mainly Triassic in age, occurs throughout south-central Montana and in central and north-central Wyoming.

The Chugwater Formation in the thesis area is believed to rest conformably upon the Embar Limestone. The basal contact of the Chugwater is locally covered but no discordance of beds or evidence of erosion was found where the contact is exposed. Thom et al. (63) suggested that the lower part of the Chugwater might be Permian in age which would indicate that no hiatus is present at the basal contact of the Chugwater. The contact between the Chugwater and the overlying Sundance Formation appears locally to be an unconformity. The strata of both formations are concordant but the light gray shales of the uppermost Chugwater are not everywhere exposed. Because of the poorly exposed nature of the upper contact, it is not certain whether the gray shales are eroded from some localities or whether they are represented laterally by a different lithology.

Richards (55) reported that pre-Jurassic erosion removed the Chugwater in central Montana. Knappen and Moulton (34) noted that the Chugwater in the Big Horn Mountains decreases in thickness from east to west and from south to north. Gardner et al. (24) state that the Chugwater Formation "pinches out" about 50 miles north of the Wyoming Border, but that several erosional remnants exist in the Big Snowy Mountains of central Montana.

Generally the Chugwater thins to the north through south-central Montana as a result of pre-Jurassic erosion. The upper contact of the Chugwater in the thesis area may represent an erosional unconformity; however, because of the limited size of the area mapped, no major discordance is discernible.

Distribution and Topographic Expression. The Chugwater Formation is a well-known ridge-former in Wyoming and southern Montana. The red color of the formation makes the ridges striking in appearance.

Shively Hill Dome in the mapped area is nearly surrounded by a steep-faced ridge formed in the Chugwater red beds (Figure 7). Much of the floor of the synclinal valley between Shively Hill Dome and North Pryor Mountain is covered by red soils from the Chugwater. West of Shively Hill Dome, in the extreme southern and southeastern parts of the thesis area, the Chugwater is extensively exposed where it forms high, flat-topped ridges and divides separated by steep-walled coulees or canyons.

The Chugwater dominantly consists of red sandstones, siltstones, and shales. The sandstones, being most resistant, form small ledges within the Chugwater ridges (Figure 8). The shale beds form gentle grass- or talus-covered slopes beneath the sandstone ledges. A thin limestone, present in the upper part of the formation, forms a white ledge distinct from the adjacent red sandstones and shales. The basal Sundance Formation consists of a thick resistant limestone which caps the Chugwater ridges in most localities.

FIGURE 7. Northeast flank of Shively Hill Dome with Chugwater cuesta. The tree-covered slope is formed on the Tensleep Sandstone. The cuesta at the far left is formed in the Sundance Formation.

FIGURE 8. Hogback of Chugwater Formation on the north flank of Shively Hill Dome. The sandstones in the formation form thin ledges in the ridge.

Lithology and Thickness. The Chugwater Formation in the mapped area consists of alternating brick red to brownish red sandstones, siltstones, and shales. The sandstones are fine-grained, silty, and impure. They are composed of subrounded to rounded quartz grains and some gypsum crystals. Calcite is the most common cement in the sandstones. They are usually red to red-brown with a few white streaks. These streaks are well-cemented and resistant indicating that the red color in some cases is post-depositional and may be entirely a function of staining from adjacent units. The sandstones grade upward into siltstones and/or shales. It is difficult to trace most units laterally except where small ledges or ribs are persistent.

The siltstones are red in color, thin-bedded and platy. They commonly grade laterally into silty shales. Gentle slopes are formed on the red silty or sandy shales of the Chugwater. Gypsum stringers are common in much of the shale in the lower part of the formation.

Nearly 30 feet above the base of the Chugwater Formation, a five-foot thick, massive gypsum bed is commonly present. Because this part of the lower Chugwater is often talus-covered, the extent or variation of the gypsum bed is not known.

A white to purple-gray limestone approximately 80 feet below the top of the Chugwater is present throughout the mapped area.

This unit ranges from two to five feet in thickness. The limestone is thin-bedded to laminated and locally shows cross-bedding or scour-and-fill on a small scale. Thin section analysis shows that some thin beds and laminations are extremely silty with a microspar matrix. Other laminations are slightly silty with a micritic matrix and local rounded micrite grains or lumps. Some laminations are composed of micrite without impurities. Richards (55) suggested that this limestone may be a northern correlative of the Alcova Limestone of central Wyoming.

A gypsum bed two and one half feet thick crops out where Hay Creek crosses Castle Butte Fault at the northwest end of Shively Hill Dome. This unit lies about 40 feet below the top of the Chugwater. The exposure in this area is limited because of faulting; therefore, the extent of this gypsum bed is unknown.

The Chugwater Formation was measured in the SW1/4 SW1/4, sec. 24, T. 5 S., R. 27 E., on the northeast flank of Shively Hill Dome, where it is nearly 450 feet thick. West of the thesis area Knappen and Moulton (34) measured slightly over 400 feet of Chugwater. Thom *et al*. (63) found that the thickest section--655 feet--of Chugwater was near the head of the West Fork of Soap Creek to the southeast of the mapped area.

Age. No fossils were found in the Chugwater Formation within the area mapped. Fossils also were not found by Knappen and Moulton (34) west of the thesis area or by Thom et al. (63) in the Crow Indian Reservation. These authors merely stated a Triassic age for this formation. Darton (17) did find marine invertebrates in the Chugwater of central Wyoming that G. H. Girty tentatively identified as partly Triassic in age. Gardner et al. (24) stated, without reference to localities, that land vertebrates and fresh water invertebrates of Triassic age were found in the Chugwater in south-central Montana.

The age of the Chugwater Formation in south-central Montana is not certain. Most sources in the literature postulate a Triassic age based on either scanty faunal evidence or stratigraphic position in relation to strata of Triassic age in adjacent areas. The red beds and gypsum beds in the lower Chugwater of the thesis area may actually be Permian in age and correlate to the upper Embar Formation of northern and central Wyoming (63). It is also possible that the uppermost beds, including the gypsum bed of the upper Chugwater, are Jurassic in age and may be correlative with the lower Gypsum Springs or Piper formations of Wyoming and Montana. These possible Permian and Jurassic beds were included in the Chugwater Formation because lithologic changes or distinctions were not well enough defined to warrant subdivisions. Additionally no fossils were found to aid in age identification.

Source Rocks and Depositional Environment. The source of the detrital material found in the Chugwater is not known. However, it appears to have been a source different from that of the coarse clastic material of the Tensleep Sandstone.

The absence of fossils in the Chugwater in the thesis area and in southern Montana makes the environment of deposition difficult to determine. The presence of thin limestone and gypsum beds might indicate a marine environment, restricted in nature and located in an arid climate. The thin limestone in the upper Chugwater does not exclude the possibility of a continental basin producing chemical precipitation.

In Wyoming and southern Montana, thin but widespread limestones interfinger with the red bed sequence of the Chugwater. In western Wyoming and southwestern Montana the red beds intertongue with a marine limestone facies to the west. Kummel (36) suggested that the sea was from the west as part of the miogeosyncline in Idaho and Utah and that the intertonguing relationship was produced by advance or retreat of the sea accompanied by retreat or advance of the red bed facies. Reeside (53) and Branson (8) agreed that the Triassic red bed sequence is primarily marine with interbedded continental strata.

The specific environments of deposition for the Chugwater

Formation are not known. It appears to contain strata of both marine and continental origins.

Sundance Formation

The Jurassic rocks in the Pryor Mountains area have been divided into two formations: the Sundance Formation and the Morrison Formation. The Sundance Formation lies over the red bed sequence of the Triassic Chugwater Formation and below the Morrison Formation. The Sundance was named by Darton (14) for a sequence of marine limestones, sandstones, and shales near the town of Sundance in Crook County, Wyoming. In central and western Montana this sequence is called the Ellis Group and is subdivided into the Piper, Rierdon, and Swift Formations.

The contact between the Sundance and the underlying Chugwater Formation in the thesis area is apparently conformable. However, as discussed in the previous section concerning the Chugwater Formation, this contact is thought to represent a regional disconformity. The upper boundary of the Sundance is not well exposed in the thesis area. Because no evidence of unconformity was found the contact between the Sundance and Morrison Formations is assumed to be conformable within the mapped area.

Distribution and Topographic Expression. The Sundance Formation in the thesis area crops out at the north end of Shively

Hill Dome and extends eastward across the southern part of the area. It is best exposed in a series of north-dipping cuestas northeast of Shively Hill Dome. Three major limestones are the most resistant units and form well-defined ridges separated by less resistant shales and claystones in strike valleys between the ridges. The lowest limestone generally caps Chugwater ridges. The middle limestone forms a sharp ridge with a very smooth dip slope. The sandy limestone at the top of the Sundance forms a low ridge in some localities and in others forms a ledge in the cuestas capped by the Pryor Conglomerate (Early Cretaceous).

Lithology and Thickness. The Sundance Formation consists of three major limestone units separated by two thick shale and claystone sequences. The limestones occur at the base, near the middle, and at the top of the formation.

The basal unit consists mainly of thick light gray to nearly white, skeletal limestones with intercalated gray claystones. The lowest part is commonly dense, sandy, and nonfossiliferous. The middle and upper beds commonly contain the pelecypod, *Camptonectes* sp. Oolites are found locally in several of the fossiliferous beds. This basal limestone sequence is up to 50 feet thick.

Above the basal limestone a thick sequence of shale and claystone is present. The lower part is a red-brown shale sequence about 30 feet thick. This unit forms reddish soils and is nonfossiliferous. The upper part of this sequence is over 100 feet thick and is light gray to yellow-gray in color. It is composed of claystones containing crinoid (Pentacrinus sp.) columnals and pelecypods of which Gryphaea sp. is the most common. Locally the pelecypod fragments are cemented with micrite and are relatively resistant forming small ledges or ridges. These ledges could represent bioherms. The base of the light gray fossiliferous claystone is correlative to the contact between the Piper and Rierdon Formations of the Ellis Group in central Montana, where the division is based on the appearance of Gryphaea in the claystone.

The middle limestone zone is eight feet thick and is even-bedded except near the base where there is cross-bedding. Thin section analysis shows this unit to be an oolitic limestone with a few shell fragments cemented by sparry calcite. It is light brown to yellowish gray in color, thin-bedded, and it contains a slight amount of glauconite at some localities. Locally a thin, soft, calcareous sandstone occurs below the oolitic limestone. The top of the oolitic limestone is correlative with the contact between the Rierdon and Swift formations of the Ellis Group.

The slope between the middle and upper limestone zones is formed on brown shales in the lower part and greenish gray claystones in the upper part. Belemnite guards and Ostrea sp. fragments litter the slopes, especially in the upper claystone unit.

The top of the Sundance Formation was placed at the top of the uppermost limestone unit. This unit is commonly poorly exposed except where it forms a small ledge below the Pryor Conglomerate cuesta. Thin section analyses of this limestone from several localities show abundant glauconite, chert, quartz, volcanic rock fragments, and pelecypod fragments. The shell fragments and the calcite cement compose between 50 to 60 percent of the rock. Chert and quartz make up nearly 25 percent of the rock and the rock fragments range slightly over 15 percent. The detrital fragments are generally fine- to medium-grained and are subangular to subrounded.

The upper limestone, as well as the claystone below it, are characterized by a green tint because of the glauconite content. This limestone also shows many current features such as small channels, lenses, cross-bedding, current ripple marks, and pelecypod shells which are generally turned over to a stable position (Figure 9). The lithology varies laterally along the strike in this unit and there are lenses and locally restricted units rather than laterally persistent beds.

A section of the Sundance Formation northeast of Shively Hill Dome was measured and found to be 355 feet thick. According to Imlay (32) the gypsum beds and red beds below the basal Sundance limestone (here included in the upper Chugwater Formation) should be included with the Jurassic rocks. If this section were added, the

FIGURE 9. The upper limestone in the Sundance Formation containing pelecypod shells. Note that most of the shells have been rotated to stable positions.

thickness in the thesis area would be nearly 400 feet. Thom *et al.* (63) measured a maximum of 680 feet in the Crow Indian Reservation. Knappen and Moulton (34) reported between 390 and 498 feet of Sundance in the region northwest of the Pryor Mountains. Richards (55) found about 500 feet of Sundance exposed along the eastern side of the Big Horn Mountains.

The variation in thickness of the Sundance Formation in south-central Montana may be attributed to the disconformity within the upper Sundance as reported by Imlay (32), to the interfingering relationship of the Sundance and overlying Morrison Formation on a regional basis, and to the relief at the Sundance-Chugwater disconformity.

Age. The age of the Sundance Formation is primarily based on the contained ammonites. Imlay (31) reported a complete faunal list for the marine Jurassic rocks of the Pryor Mountains area. Fossils found in the Sundance of the thesis area include *Camptonectes* sp., *Gryphaea* sp., *Pachyteuthis densus* (?), *Ostrea* sp., *Pentacrinus* sp., and several unidentified pelecypods. This assemblage is similar to that of Imlay. These fossils and the ammonites reported by Imlay date the lower Sundance, up to the claystone containing *Gryphaea*, as being Middle Jurassic in age, and the remaining upper part of the Sundance Formation as Late Jurassic.

Source Rock and Depositional Environment. Several types of carbonate rock were found in the Sundance Formation. The middle limestone unit is an oolite indicating a shallow, warm, agitated sea. The basal and uppermost limestone sequences contain abundant fragmental pelecypod shell material which indicates normal shallow marine water on either an open shelf or within the littoral zone. The cross-bedding and shell fragmentation indicate that these limestones were deposited above wave base. The mudstones are calcareous and formed from silty lime muds which could have been deposited in a shallow bay, behind a barrier of some type, or in a deeper zone below wave base. In any event the environment permitted an abundant growth of pelecypods.

The upper limestone sequence contains a high percent of detrital material. A sedimentary provenance is indicated by the abundance of chert and quartz. The fine-grained rock fragments indicate a volcanic source within the sedimentary terrane. The majority of the carbonate rocks, except for the oolites, appear to be organic rather than chemical in origin.

The entire Sundance Formation was formed in a relatively shallow sea as indicated by the types of fossils found and the presence of glauconite. The varying lithology appears to be a product of slight changes in water depth and the position of the wave base.

Morrison Formation

The Morrison Formation was named by C. H. Eldridge (23) for a sequence of nonmarine shales and dirty sandstones found near Morrison, Colorado. The name Morrison is applied in south-central Montana to a continental sequence of sandstones and varicolored shales which lies above the Jurassic Sundance Formation and below the Early Cretaceous Cloverly Group. Darton (16) was the first geologist to correlate the Morrison from Colorado to the Big Horn Mountains and South Dakota.

The contact between the Morrison Formation and the underlying Sundance Formation is not well exposed in the thesis area because the basal Morrison forms a covered shale valley or slope. Where the contact is visible no discordance could be detected, and the contact appears to be conformable.

Imlay *et al.* (33), Knappen and Moulton (34), and Richards (55) reported an interfingering relationship between the continental Morrison and the marine Sundance. Although such a contact represents a change in environment, no hiatus seems to be present.

The upper contact of the Morrison with the overlying Pryor Conglomerate is an erosional unconformity without noticeable angular discordance. The Pryor Conglomerate was deposited in channels in the top of the Morrison.

Distribution and Topographic Expression. The Morrison Formation is widespread. It is found from the central Rocky Mountains of Colorado north into Wyoming and southern Montana and east to the Black Hills region of South Dakota. The most notable characteristics are varicolored shales and discontinuous sandstones which contain a continental flora and fauna of Jurassic age.

The exposures of the Morrison in the mapped area are generally of poor quality. The formation forms slopes or valleys between the Sundance and Cloverly ridges. The Morrison crops out north of Shively Hill Dome and extends eastward across the southern part of the thesis area. The sandstones which appear abruptly in the formation form discontinuous ridges. The shales and claystones are best exposed where they lie below the ridge-forming Pryor Conglomerate or Morrison sandstones.

Lithology and Thickness. The Morrison Formation characteristically displays a varied lithology. Commonly there are varicolored shales and claystones interbedded with sandstones which occur as lensing channel deposits.

Because exposures of the Morrison generally are poor, no single shale or claystone unit could be traced laterally for any distance except for the red silty shale at the base which forms a red soil above the Sundance. Red, brown, tan, green, and gray shales and claystones crop out at various localities in the thesis area.

The sandstone beds generally occur near the middle of the formation. They commonly overlie a tan claystone. At some localities only a single sandstone is present, but northeast of Shively Hill Dome two sandstone units crop out. One sandstone is stratigraphically near the middle of the formation, and the other lies a few feet below the top of the formation. Both of these sandstones pinch out laterally (Figure 10). In a section measured about three miles east of Shively Hill Dome, two sandstones are again present but they are both near the middle of the formation separated by 35 feet of brown shale.

The sandstones are very fine- to fine-grained and consist of nearly 90 percent subangular to subrounded quartz. There are minor amounts of tourmaline, magnetite, and chert. The sandstones are moderately to well-cemented with calcite. Planar cross-bedding is common to the sandstones of the Morrison.

The Morrison Formation in the mapped area is about 170 feet thick. The thickness varies slightly because of the erosional unconformity at the top of the formation. Elsewhere the thickness of the formation varies greatly and Thom *et al.* (63) reported between 79 and 400 feet in the Crow Indian Reservation. No thickness trends are evident on a regional basis.

Age. Vertebrate bone fragments were found in a tan shale northwest of Shively Hill Dome. Bone material was also found at

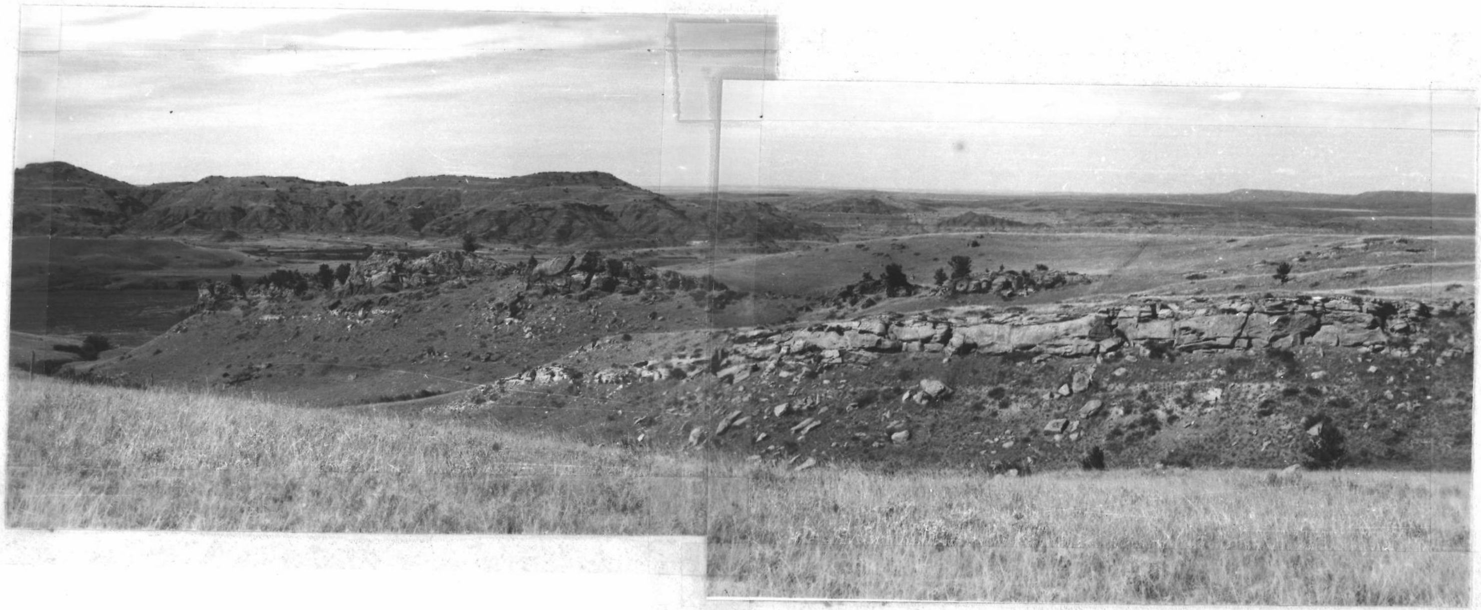


FIGURE 10. The ridge in the foreground is formed by a lensing sandstone in the Morrison Formation. The second ridge is capped by the Pryor Conglomerate which occurs in channel deposits. Note the thin light-colored Morrison sandstone in the second ridge immediately below the Pryor Conglomerate.

this locality in a 15-foot sandstone bed overlying the tan shale. Diplodocus, a terrestrial dinosaur, was reported by Mook (44) from the Morrison east of the thesis area. From coal beds in the upper Morrison of central Montana, Brown (9) described plant fossils which indicate a Late Jurassic age. Peck (48) reported ostracods of Late Jurassic age from the Morrison Formation in Montana. The Morrison in the thesis area is considered to be Late Jurassic in age because of faunal and floral evidence from adjacent areas.

Source Rock and Environment of Deposition. The sandstones in the Morrison Formation consist of quartz with minor amounts of chert and an impoverished heavy mineral suite. The sandstones are mature and either were subjected to a long period of transportation or were recycled from older sandstones. A sedimentary source is indicated for the chert component of the sandstones. The source of the components of the shales and claystones is not known.

The fauna and flora contained in the Morrison in Montana indicate a continental environment of deposition. Terrestrial dinosaurs, fresh water ostracods, and coal beds supply evidence for terrestrial, lacustrine, and swamp environments. The sandstones in shallow lenses or channels indicate a fluvial environment of deposition.

Cloverly Group

The sequence of rocks which lies unconformably upon the Late Jurassic Morrison Formation is primarily continental in origin. In the Pryor Mountains these Early Cretaceous rocks are readily divided into three units on the basis of distinctive lithologies. The lowest unit consists of conglomerates and sandstones, the middle unit is composed of varicolored shales, and the upper unit consists of silty shales and sandstones.

The formal names given to the Early Cretaceous continental rocks vary throughout the northern Rocky Mountain and northern Great Plains region. In central and southwestern Montana these rocks are included in the Kootenai Formation. In the Big Horn Basin of Wyoming this sequence is called the Cloverly Group. In the eastern Powder River Basin of Wyoming these rocks are included in the Inyan Kara Group. The Kootenai Formation, the Cloverly Formation, and the Cloverly Group are all used in south-central Montana to name the same sequence of Early Cretaceous rocks.

Darton (16) named the unit overlying the Morrison Formation the Cloverly Formation. The type locality for the Cloverly Formation is 15 miles northeast of Basin, Wyoming near Cloverly where Darton found a sequence of reddish-purple clay underlain by a coarse, buff, dirty, cross-bedded sandstone. Darton suggested that the Cloverly rocks correlated to the Fall River Sandstone, the Fuson Shale, and the Lakota Sandstone of the Black Hills in South Dakota.

In the thesis area the continental rocks overlying the Morrison Formation and underlying the Thermopolis Shale are called the Cloverly Group. This group is readily divided into three formations on the basis of distinct, mappable lithologies. The lowest formation is a basal conglomerate and pebbly sandstone overlain by cross-bedded sandstone. This unit was named the Pryor Conglomerate by Hares (26) and correlates with the Lakota Sandstone of the Black Hills and Big Horn Basin. The middle formation, consisting of varicolored shales, is called the Fuson Shale and can be correlated with the same formation in the Black Hills, the Powder River Basin, and the Big Horn Basin (Table 1). The upper formation is composed of lenticular sandstones at the base overlain by a sequence of silty shales and thin-bedded silty sandstones. The lowest sandstone in this unit, called the Greybull Sandstone by Thom et al. (63), is correlated by them with the Greybull Sandstone described by Hewett and Lupton (30) in the Big Horn Basin of Wyoming. The overlying interbedded silty shales and sandstones were called the "Rusty Beds" by Washburne (66). The "Rusty Beds" have been placed in either the Cloverly Group or in the Thermopolis

Shale by various authors. They are included in the Cloverly Group in the thesis area because Love et al. (39) found plant fossils in them similar to fossils found in the underlying Fuson Shale. Moreover, the shale containing the Greybull Sandstone is similar in appearance to parts of the "Rusty Beds". This upper unit, consisting of the Greybull Sandstone and the "Rusty Beds", is generally believed by Haun and Barlow (27) to be correlative to the Fall River Sandstone of the Powder River Basin. This unit will be referred to as the "Rusty Beds" in the following discussion.

Pryor Conglomerate

Hares (26) named the conglomerate resting unconformably on the Morrison Formation in the Pryor Mountains region the Pryor Conglomerate. The Pryor Conglomerate is considered to be the oldest formation of the Cloverly Group.

The basal part of the Pryor Conglomerate was deposited in channels cut in the underlying Morrison Formation. There is no apparent angular discordance between the beds of the Morrison and the Pryor Conglomerate at this erosional unconformity within the mapped area.

The upper part of the Pryor Conglomerate consists of fine- to coarse-grained sandstone with local pebble zones. These beds are relatively persistent in the mapped area rather than being localized channel deposits. Being located on the dip slope side of the Pryor Conglomerate ridge, the contact between this upper sandstone and the overlying varicolored shales of the Fuson Shale is not well exposed because it is generally covered. No apparent discordance or unconformity was observed anywhere, and the contact is assumed to be conformable and transitional upward into the overlying shales.

Distribution and Topographic Expression. The Pryor Conglomerate forms a north-dipping cuesta at the north end of Shively Hill Dome and extends eastward paralleling the Jurassic ridges in the southern part of the thesis area. Where the conglomerate occurs as channel-fill, the ridge is well-defined. Where the conglomerate is absent and only the overlying sandstone is present, the ridge is topographically lower and the sandstone is poorly exposed.

Lithology and Thickness. The lower part of the Pryor Conglomerate consists of pebble conglomerates and pebbly sandstones in channel deposits. The channels range from 15 to 45 feet in depth and are up to 200 feet wide. The channel deposits characteristically have both planar and trough cross-bedding. Some cross-bedded units consist entirely of conglomerates; others are sandstones which locally have a pebble layer at the base of the cross-bed (Figure 11). The channel deposits tend to become finer-grained in the upper part. The upper beds are commonly coarse-grained sandstone with isolated pebbles or pebble layers. The cross-bedding in the upper part is well-displayed and is generally the planar type (Figure 12).

The pebbles in the conglomerates are rounded; some are pitted, others are slightly polished. They range in size up to 35 millimeters and average between ten and 15 millimeters measured along the intermediate diameter. The pebbles are dominantly black, gray, and tan chert, and subordinately quartzite and granitic material.

Overlying the conglomeratic channel deposits is a sequence of laterally persistent cross-bedded sandstones which forms the ridge in the absence of the conglomerates. The sandstones are fine- to medium-grained and moderately to well-sorted. They consist mainly of quartz grains which were rounded prior to deposition, but now are angular to subangular because of authigenic quartz overgrowths. Chert and white clay form subordinate constituents. In some zones the sandstones and conglomerates are permeable.

The conglomerate sand matrix is mainly cemented by quartz. Carbonate cement occurs locally. The sandstones above the conglomerate zone are usually calcareous, and several thin beds are extremely calcareous and resemble crystalline limestones in the hand specimen. Microscopic inspection shows that these beds are actually fine-grained calcareous quartz arenites.

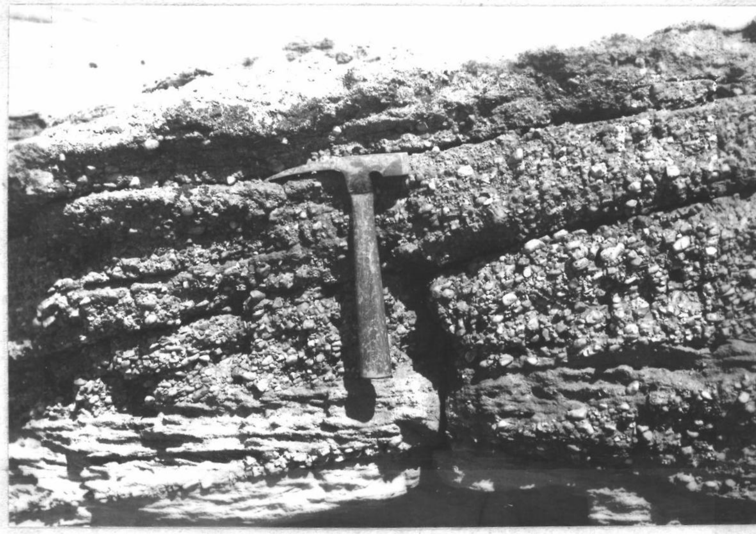


FIGURE 11. Planar cross-bedded Pryor Conglomerate. The sandstone at the bottom contains a pebble layer at the base of the cross-bed.

FIGURE 12. Hoodoos formed in the Pryor Conglomerate. Both trough and planar cross-bedding are displayed. Note the unidirectional current flow to the east indicated by the cross-beds.

The Pryor Conglomerate varies in thickness because of the channel deposits at the base. The formation in the thesis area ranges from 20 to 65 feet in thickness with the average near 50 feet.

Age. The age of the Pryor Conglomerate is Early Cretaceous. Brown (9) found plant fossils which indicated an Early Cretaceous age for the Cloverly Group. He did not find fossils in the Pryor Conglomerate but he suggested that the unconformity at the base of the formation represents the boundary between the Jurassic and Cretaceous Systems. Lammers (37) designated the conglomerate as being Early Cretaceous on the basis of structural evidence.

Source Rock and Depositional Environment. The pebbles in the conglomerates consist primarily of chert with subordinate amounts of quartzite. The abundant chert indicates a sedimentary source. Knappen and Moulton (34) suggested that the chert and limestone pebbles they found in the Pryor Conglomerate west of the thesis area were derived from the Amsden and Madison Limestones. Lammers (37) reported that the Pryor Conglomerate contains limestone pebbles to the west but none to the east, and that the size of the pebbles gradually decreases to the east. He suggested that the source area was west. Moberly (42) stated that the components of the Pryor Conglomerate were derived from reworked sedimentary rocks west of the depositional area.

The depositional environment for the conglomerates was fluvial.

The conglomerates are discontinuous and fill channels in the underlying Morrison Formation. The cross-bedding indicates unidirectional currents dominantly flowing toward the east.

The sandstones overlying the conglomerates are possibly fluvial in origin also. The decrease in grain size could indicate the lowering of the source area by erosional processes or could be attributed to decreasing velocity and competence of the transporting media. The depositional environment for the upper sandstones is not clear because of their poorly exposed nature and lack of distinguishing characteristics. Knappen and Moulton (34) suggested a possible eolian origin for part of these sandstones.

Fuson Shale

Darton (15) described a sequence of shales and clays, varicolored to black, which separates the "Dakota" Sandstone from the Lakota Sandstone in the Black Hills of South Dakota. He named the shales and clays the Fuson Shale for the exposures in Fuson Canyon near Buffalo Gap, Fall River County, South Dakota. A similar sequence of shales is found in northern Wyoming and southern Montana. The varicolored shales lying between the Pryor Conglomerate and the "Rusty Beds" in the thesis area are called the Fuson Shale because they are stratigraphically correlative to the rocks at the type section as defined by Darton.

The contact between the Fuson Shale and the underlying Pryor Conglomerate, though poorly exposed, appears to be transitional. The sandstones in the upper Pryor Conglomerate are interbedded with shales. Thom et al. (63) reported that the contact elsewhere in the Crow Indian Reservation is located in interbedded sandstones and shales.

The Fuson Shale is in transitional contact with the overlying "Rusty Beds". The shales and claystones of the Fuson grade upward into brown silty shales of the "Rusty Beds" which locally include the Greybull Sandstone correlative.

Distribution and Topographic Expression. The Fuson Shale is widespread and is found in the Black Hills, south-central Montana, and in the Powder River and Big Horn Basins of Wyoming. The formation is best exposed in slopes below the ridge formed by the "Rusty Beds" in the south-central part of the thesis area (Figure 13). The upper part of the formation is exposed in the northwest part of the thesis area on Deep Creek where the creek turns west to join Pryor Creek (Plate 3). In the lower Beauvais Creek valley the upper Fuson is exposed beneath ledges or small bluffs formed by the "Rusty Beds".

Lithology and Thickness. The shales and claystones of the upper Fuson do not form a constant sequence in the thesis area. At differing localities gray, brown, or yellow-brown shales were

FIGURE 13. Varicolored shales and claystones of the Fuson Shale exposed in a ridge capped by the "Rusty Beds" in the south-central part of the thesis area.

found underlying the "Rusty Beds". The lower Fuson Shale is exposed only in the "Rusty Beds" cuesta in the south-central part of the mapped area, and consists of blue-gray, red, maroon, lavender, or tan shales and claystones. The thickest units are blue-gray or red in color and constitute over half of the total formation.

Bentonite is a major constituent of the blue-gray claystones. Where weathered, these claystones display the typical "popcorn" surface. The bentonite component represents Eary Cretaceous volcanic activity in the source area. A lenticular sandstone near the base of the Fuson also contains bentonite as a component of the matrix.

Thin lenticular sandstones are found in the Fuson Shale at several localities. The best exposed lens occurs near the middle of the formation in the south-central part of the area. This fine-grained unit pinches out in three directions and ranges in thickness from three to zero feet in approximately 50 feet (Figure 14).

Gastroliths occur in abundance at the base of the Fuson slope. They are found in place in a 14-foot red shale near the middle of the formation. Vertebrate fossils also are common to the Fuson. The polished gastroliths are thought by some paleontologists to have been used in the digestive systems of the fossil reptiles found in the Fuson. However, these polished pebbles can be interpreted as true gastroliths only when found in a pile located

FIGURE 14. A thin sandstone lens in the Fuson Shale. The maximum thickness is three feet in the center of the ledge. The sandstone unit in the foreground is part of the upper "Rusty Beds".

in the body cavity of a vertebrate skeleton (45). During the 1965 field season, three incomplete fossil vertebrate skeletons were removed from the Fuson Shale in the thesis area by an expedition from Peabody Museum led by J. H. Ostrum. The results of these finds are at present unpublished.

The thickness of the Fuson Shale in the mapped area is nearly 110 feet. Thom et al. (63) and Knappen and Moulton (34) reported slightly over 100 feet of Fuson elsewhere in the Pryor Mountains area.

Age. Love et al. (39) and Peck and Craig (49) reported Early Cretaceous fossils, mainly ostracods, from the varicolored shales overlying the Pryor Conglomerate. These fossils and the stratigraphic position of the Fuson Shale indicate an Early Cretaceous age.

Source Rocks and Depositional Environment. Bentonitic shales and claystones with subordinate lenticular sandstones compose the Fuson Shale. Moberly (42) proposed swamp and lacustrine environments for the lower part of the Fuson Shale. He compared the upper Fuson units to soils formed under savannah conditions. The bentonitic component of the claystones and shales indicates a volcanic source, and Moberly (43) theorized that much of the volcanic ash material was blown into the area from volcanic eruptions to the west. The lensing sandstones in the Fuson are probably fluvial channel deposits.

"Rusty Beds"

A sequence of interbedded sandstones, siltstones and shales overlying the Fuson Shale was first named the "Rusty Beds" by Washburne (66) in the northern Big Horn Basin of Wyoming. The name, "Rusty Beds", is not of formational rank but is an informal term commonly used to describe the rocks lying between the Fuson Shale and the Thermopolis Shale. The "Rusty Beds" are stratigraphically correlative to the Fall River Sandstone of the Powder River and Big Horn Basins (Table 1). The name, "Rusty Beds", is used to describe the upper formation of the Cloverly Group in the thesis area. No formational name has been designated for this sequence in south-central Montana.

The "Rusty Beds" are in transitional contact with the underlying Fuson Shale. The varicolored shales and clays of the Fuson grade upward into the brown silty shales and siltstones of the lower "Rusty Beds". No evidence was found in the mapped area to indicate the unconformity at the base of the "Rusty Beds" reported by Washburne. The upper contact of the "Rusty Beds" with the Thermopolis Shale is also transitional. The top of the "Rusty Beds" is arbitrarily placed at the top of a silty sandstone and siltstone sequence which forms a low ridge or bluff above the Fuson Shale slopes.

Topographic Expression. In the south-central and southeastern parts of the thesis area the "Rusty Beds" form a ridge. Where the strata are nearly flat-lying, as on lower Deep Creek in the northwestern part of the area and on Beauvais Creek in the eastern and southeastern part of the area, they form discontinuous bluffs or ledges in the upper valley slope (Figure 15).

Lithology and Thickness. Contained in the brown shales and siltstones of the lower "Rusty Beds" is a lenticular sandstone which may be correlative with the Greybull Sandstone in the Big Horn Basin (Figure 16). The maximum thickness of this channel sandstone was found on Deep Creek where it is seven feet thick and pinches out within 100 yards laterally. This sandstone consists mainly of very fine- to fine-grained quartz, is cross-bedded, and is mottled yellow and brown with white streaks. In the south-central part of the thesis area this unit is rarely present.

The upper "Rusty Beds" consist of interbedded rusty colored siltstone and sandstones and brown silty shales (Figure 17). The sandstones are very fine-grained and well-sorted. The sandstones consist mainly of subangular quartz grains with a few zircon grains. The matrix consists of clay and limonite from which the rusty color is derived. The sandstones display minute scour-and-fill structures, cross-laminations, and bottom markings. The origin of the bottom markings is unknown. Oscillation and current ripple marks are common to the siltstones and sandstones.

FIGURE 15. The small bluffs at the top of the slope are formed by the "Rusty Beds". The light-colored unit below the bluffs is the upper Fuson Shale. This outcrop is on Beauvais Creek.

FIGURE 16. The lenticular sandstone below the "Rusty Beds" bluff is the Greybull Sandstone correlative. The exposure is on Beauvais Creek.

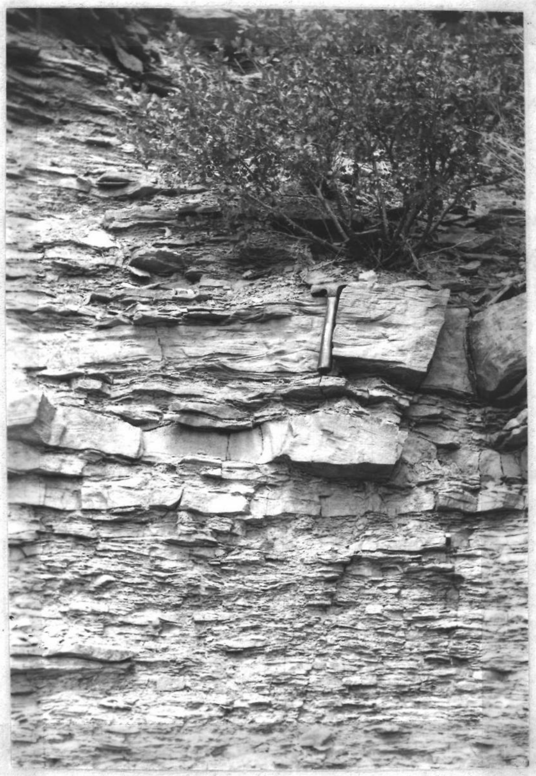


FIGURE 17. A sequence of interbedded sandstones, siltstones, and shales typical of the upper "Rusty Beds" on Deep Creek.

The "Rusty Beds", including the lower lenticular sandstone, range in thickness from 90 feet on Deep Creek to 50 feet on Beauvais Creek. The interfingering relationship of the upper "Rusty Beds" with the overlying Thermopolis Shale is the cause of the thickness variation.

Age. Early Cretaceous fossils were reported from the Fuson Shale by Peck and Craig (49). Eicher (22) reported Early Cretaceous fossils from the Thermopolis Shale. Because the "Rusty Beds" lie between the Fuson and the Thermopolis, they are Early Cretaceous in age by stratigraphic position. Love *et al.* (39) found plant fossils in the "Rusty Beds" similar to those found in the underlying Fuson Shale.

Source Rocks and Depositional Environment. Moberly (43) reported that many types of clay minerals derived from ancient rocks are present in the "Rusty Beds". He suggested that, during the Early Cretaceous transgression, rivers flowing into the sea carried clays from many sources.

The "Rusty Beds" represent a transitional zone between the nonmarine Fuson Shale and the marine Thermopolis Shale. The interbedded shales, siltstones, and sandstones indicate episodic quiet water and current deposition. The sedimentary structures and the presence of some plant material indicate nearshore, shallow water deposition. Moberly suggested deposition of the

"Rusty Beds" occurred in a tidal flat environment at the margin of the transgressing Early Cretaceous sea.

Thermopolis Shale

Lupton (40) first defined the Thermopolis Shale for the dark shale sequence exposed near Thermopolis, Wyoming. In his original definition Lupton included the black shale interval above the upper sandstone of the Cloverly, the Muddy Sandstone, and the shale sequence between the Muddy and the Mowry Shale. Many contemporary Rocky Mountain geologists include only the shales below the Muddy in the Thermopolis, and they designate the interval above the Muddy Sandstone as the Shell Creek Shale. Following Lupton's scheme, the Thermopolis Shale in the thesis area is divided into three members: the Lower Thermopolis Shale Member, the Birdhead Sandstone Member, and the Upper Thermopolis Shale Member.

The Lower Thermopolis Shale Member is in transitional contact with the underlying "Rusty Beds" of the Cloverly Group. The siltstones, sandstones, and shales of the Cloverly Group gradationally pass upward into black shales with interbedded siltstones of the Lower Thermopolis. The upper contact of the Thermopolis with the Mowry Shale is also gradational and the contact is arbitrarily placed at the base of the first shale bed above the Birdhead Sandstone which contains fish scales in abundance.

Distribution and Topographic Expression. The Thermopolis Shale crops out in nearly all of the northern two-thirds of the thesis area. The Lower Member is exposed in the major creek valleys and forms a poorly defined ledge or rim in the thesis area. The Upper Member forms broad, flat, gently north-sloping plains in the central part of the area which are underlain by the Birdhead Sandstone. The Upper Member also forms shale badlands around Woody Divide and in the area of Black Mountain. Slumping is common in the Thermopolis around Woody Divide and along the creek valleys.

Lithology and Thickness. The Thermopolis Shale is divided into three members on the basis of lithology (Figure 18). The Lower Thermopolis Shale Member generally consists of dark gray to black fissile shale with interbedded siltstones and a few thin bentonite beds in the upper part. Two siltstone zones ten to 15 feet thick are persistent in the Lower Member, one about 100 feet, and the second about 225 feet above the base. These zones are characterized by thin-bedded (less than one foot) gray to rusty brown siltstones interbedded with black fissile shales. The siltstones contain carbonaceous matter and are cross-laminated. Also persistent in the area is a zone of dahllite concretions about 80 to 90 feet above the basal contact. The concretions are spherulitic at some localities, and botryoidal at others.

The Birdhead Sandstone is the middle member of the

FIGURE 18. The three members of the Thermopolis Shale at the south end of Woody Divide. The units are the Mowry Shale (Kmr), the Upper Thermopolis Shale Member (Kut), the Birdhead Sandstone Member (Kbh), and the Lower Thermopolis Shale Member (Klt).

Thermopolis Shale. These sandstones are generally very fine- to fine-grained, quartzose, and have a salt-and-pepper appearance. The Birdhead is commonly light gray to yellow gray and forms a light-colored zone in contrast to the enclosing black shale members. The Birdhead Sandstone is discussed in detail in a following section.

The Upper Thermopolis Shale Member closely resembles the Lower Member and was probably deposited under similar conditions. This member generally consists of dark gray to gray brown shales with ironstone layers and concretions. Bentonite beds and bentonitic shales are common, and a bentonite bed two feet thick containing a thin (1/4 to 1/2 inch) splintery pencil shale occurs everywhere above the Birdhead Sandstone. Approximately 10-20 feet above the Birdhead, marine vertebrate fossil remains are found in abundance. The fossils collected by the writer were identified by Dr. J. H. Ostrom (45) as:

Shark spines and teeth	Asteracanthus sp. Synechodus sp.
Holostean fish scales and vertebrae:	Lepisosteus sp. Indeterminate species
Turtle shell fragments:	Glytops sp.
Crocodile vertebrae, femur, scutes, teeth, tibia:	(?) Crocodylus sp.
Plesiosaur vertebrae, teeth, humerus, ischium:	(?) Trinacrimerum sp.

In the zone 20-50 feet above the Birdhead Sandstone there are numerous sandstone dikes (Figure 19). Most of these dikes have the same lithology as the Birdhead Sandstone except that authigenic glauconite is much more abundant in the dikes. There are two types of dikes. The more common type consists of feldspathic lithic arenites with shale inclusions and carbonate cement. The second type is composed of rounded clay and shale pebbles included in a silty clay matrix and siderite cement.

Approximately 110 feet above the Birdhead a laterally persistent zone containing ironstone layers and concretions is present. The ironstone layers are four to ten inches thick.

Four sections of the Thermopolis Shale were measured in the thesis area. The Lower Member ranges from 330 to 350 feet in thickness, the Birdhead Sandstone Member is between 10 and 16 feet thick, and the Upper Member is about 400 feet thick. The total thickness of the Thermopolis Shale in the thesis area ranges from 740 to 766 feet.

Age. The Thermopolis Shale is Early Cretaceous in age based on stratigraphic position and fossil material. Ammonites found in the overlying Mowry Shale are Early Cretaceous forms. The ostracods and fossil plant remains in the underlying Cloverly Group also are Early Cretaceous in age. Eicher (22) found Early Cretaceous planktonic foraminifera in the Thermopolis of the

FIGURE 19. Vertical sandstone dike in the Upper Thermopolis Shale Member near Black Mountain.

Big Horn Basin. Cobban and Reeside (11) found Early Cretaceous ammonites in the upper Thermopolis in the northwestern part of the Big Horn Basin.

Source Rocks and Depositional Environment. The shales of the Thermopolis are generally black and carbonaceous. The main clay mineral in these shales, according to Moberly (43), is montmorillonite. A large percent of the clay in the Thermopolis Shale was derived from altered volcanic ash as indicated by the bentonite beds and bentonitic shales. The source of the Birdhead Sandstone is discussed in detail in a following section.

The black shales were deposited in a marine environment as indicated by the presence of marine foraminifera and marine vertebrates such as plesiosaurs. The black carbonaceous character of the shales represents restricted, toxic bottom conditions. These bottom conditions are also indicated by the undisturbed laminated shales and the absence of bottom dwellers. The cross-laminated siltstones in the lower member may represent very shallow water or tidal flat environments. These silty units are similar in character to the "Rusty Beds" of the underlying Cloverly Group. Moberly (43) and Eicher (22) agreed that the black shales were deposited in shallow marine waters with toxic bottom conditions rather than in deep marine waters.

Mowry Shale

The Mowry Shale was first described by Darton (16) at its outcrop on Mowrie Creek northwest of Buffalo, Johnson County, Wyoming. The formation consists of gray siliceous shales with intercalated thin siltstones and sandstones. This formation characteristically contains abundant fish scales and is commonly referred to in the literature as the "fish scale beds".

The contact between the Mowry and the underlying Thermopolis Shale is placed at the lowest shale unit bearing fish scales. The black fissile shales of the upper Thermopolis transitionally pass upward into the gray or brown fish scale-bearing shales of the Mowry. The Mowry contains more silt, included in the shales and in the form of siltstones, than the Thermopolis. The position of the lowest fish scale-bearing shale unit nearly coincides with a subtle color and lithology change. The stratigraphic position of the lower Mowry contact was found to be nearly constant in three measured sections in the thesis area.

The Mowry Shale is the youngest formation mapped in the thesis area. The upper part of the Mowry is presently being removed by erosion. The contact between the Mowry and the overlying Frontier Formation was observed in a section located on Pryor Creek northwest of the area where it appeared to be transitional. Knappen and Moulton (34) reported that this upper Mowry contact is transitional in the area northwest of the Pryor Mountains.

Distribution and Topographic Expression. The Mowry Shale is a widespread ridge- or escarpment-forming unit in the Northern Great Plains region. Because of its siliceous character this formation is more resistant than the adjacent formations. The Mowry can be traced from the Black Hills into central and southern Montana and also into northern and central Wyoming. The Mowry caps prominent benches or divides in the Pryor Mountains of south-central Montana.

Woody Divide is the most prominent topographic feature in the northeastern quarter of the thesis area. This escarpment is capped by the Mowry Shale and rises from 500 to 700 feet above the adjacent creek valleys (Figure 20). The Mowry forms smooth, steep slopes on the sides of the divide above the dissected shale badlands formed on the Thermopolis Shale. The top of the Mowry divide is relatively smooth and slopes gently inward. This surface is littered with residual siltstone and sandstone rubble. The Mowry Shale is preserved on Woody Divide because of its resistant nature and because it is in the center of a gently north-plunging syncline.

Lithology and Thickness. The two most characteristic features of the Mowry Shale are its siliceous nature and the presence of

FIGURE 20. The west side of Woody Divide (left skyline) as seen from Shively Hill Dome. The divide is capped by the resistant, siliceous Mowry Shale.

abundant fish scales. The unit immediately above the Upper Thermopolis Shale is a light gray shale containing abundant red-brown and black fish scales. Overlying this shale unit there are gray and yellowish tan shales, claystones, and bentonites with interbedded siltstones. Some of the siltstones contain abundant biotite flakes.

Approximately 145 feet above the base of the Mowry, there is a siliceous sandstone. This unit, although less than one foot thick, is persistent and was found at several localities on the west side of Woody Divide. The major constituents are fine-grained quartz, black rock fragments, and fish bones and scales.

Near the middle of the formation, there is a series of thin siltstones, ranging in thickness from one inch to one foot, interbedded with shales. The siltstones are finely laminated and contain abundant fish scales. A few poorly preserved ammonites were collected from this zone. These siltstones are dark to light gray when fresh but weather to a medium brown.

A second persistent sandstone unit occurs about 200 feet above the base of the Mowry. This bed is three to four feet thick and is composed of very fine-grained quartz, biotite, rock fragments, and fish bone and scale fragments. A few black chert pebbles are present at the base of the bed. This well-cemented sandstone is resistant and forms thin ledges in the rims of coulees cut into the sides of the divide.

The upper part of the Mowry Shale consists of light gray and tan shales, silty claystones, and thin siltstones. The silt content in the upper Mowry appears to be greater than in the lower Mowry. Bentonite beds and bentonitic claystones are also present in this upper part.

The Mowry Shale section is incomplete in the thesis area as a result of present erosion. The maximum thickness exposed in the mapped area is about 250 feet. Thom *et al.* (63) reported 300 feet of Mowry in Pryor Creek Valley northwest of the area.

Age. The abundant fish remains found in the Mowry are fragmented and are virtually useless for age determination. Ammonites found in the Mowry are not abundant but are the basis of age determination. Reeside and Cobban (54) reported uncrushed ammonites from the Mowry Shale of south-central Montana. They found and named one genus, *Neogastroplites* in the Pryor Mountains area. They assign a late Albian (late Early Cretaceous) age to this ammonite. The ammonites found in Pryor Creek valley and in the thesis area are poorly preserved but closely resemble *Neogastroplites* as described by Reeside and Cobban.

Source Rocks and Depositional Environment. The Mowry Shale consists of bentonites, siliceous shales and claystones, laminated siltstones, and silty sandstones. The bentonite is derived from altered volcanic ash. The quartz silt and sand appear to be similar to that found in most normal marine clastic deposits. The rock fragments in the sandstones are of unknown origin. The origin of the siliceous material in the shales and claystones is a controversial subject.

The origin of the siliceous material of the Mowry was treated in detail by Rubey (57). He concluded that the silica in the shales and claystones was derived from dissolved volcanic ash. He stated that as the volcanic ash slowly settled through the marine waters much silica was taken into solution and was later precipitated by decaying organic matter. Davis (19), in a more recent study, reported that the chemical data used as the basis of Rubey's hypothesis was erroneous. He felt that the siliceous material was not derived from ash because of the differences found between the chemical nature of the bentonites and the silica in the shales. He also pointed out that recent work indicated that silica precipitation is not dependent on Eh as suggested by Rubey. Davis found well-preserved radiolarian tests in much of the Mowry, and concluded that the silica was derived from the siliceous tests or organisms in a normal marine environment.

Ammonite and radiolarian fossils indicate a marine environment for the Mowry. The fine laminations in the siltstones and the many undecayed fish scales and bones indicate the absence of bottom dwellers. The lack of bottom dwellers suggests that the bottom zone was toxic. Davis (19) suggested that the sediment interface was toxic, hence no bottom dwellers could exist. He felt that the water above the bottom was not toxic and that bottom scavengers, dominantly fish, were responsible for the absence of complete fish skeletons.

Birdhead Sandstone

The Birdhead Sandstone was first defined by Thom *et al.* (63) as the middle member of the Thermopolis Shale in the Crow Indian Reservation region. The name was derived from the exposure in Birdhead Coulee in T. 3 S., R. 27 E., Yellowstone County, Montana. Wulf (72) recently designated a more specific type locality in the NW1/4 sec. 9, T. 3 S., R. 27 E., Yellowstone County, Montana. The section at the type locality is not well exposed and is the thinnest section found in the Pryor Mountains region. In addition to the poor exposure of the Birdhead at the type locality, this section is not easily accessible. A section measured in the center of the W1/2 sec. 29, T. 3 S., R. 27 E., Yellowstone County, Montana, is well-exposed and displays both contact relationships.

This section is proposed as a reference section because it is readily accessible and is more typical of the majority of the Birdhead exposures.

Cobban and Reeside (11) considered the Muddy Sandstone of the Big Horn Basin, the Newcastle Sandstone of the Black Hills and northeastern Powder River Basin, and the Birdhead Sandstone of Big Horn County, Montana, to be correlatives (Table 1). Wulf (72) reported that the Newcastle Sandstone of the Powder River Basin is correlative to the Birdhead Sandstone in south-central Montana. Paull (46) considered the Muddy Sandstone of the Big Horn Basin to be correlative to the sandstone member of the Thermopolis shale as mapped by Knappen and Moulton (34). The sandstone mapped by Knappen and Moulton north and west of the Pryor Mountains was found by the writer to be laterally continuous with the Birdhead Sandstone at its type locality.

The Birdhead Sandstone crops out almost continuously through the western part of the Crow Indian Reservation and north and west of the Pryor Mountains where it forms a ledge between the upper and lower members of the Thermopolis Shale. Northwest of the thesis area, in Pryor Creek Valley, the Birdhead is resistant and forms a steep-faced rim or ledge. However, in the thesis area the Birdhead is less resistant and forms a poorly defined outcrop.

It is mainly delineated by a light-colored layer or band which is in marked contrast with the dark gray or black color of the upper and lower members of the Thermopolis Shale.

The Thermopolis Shale is Early Cretaceous in age by stratigraphic position. The underlying Cloverly Group and the overlying Mowry Shale are both Early Cretaceous in age. The foraminifera and pelecypods found in the Thermopolis Shale also indicate an Early Cretaceous age (Wulf 72). The Birdhead Sandstone is the middle member of the Thermopolis Shale and therefore must also be Early Cretaceous in age by stratigraphic position. Wulf designated a Late Albian age for the Birdhead Sandstone.

Vertical Stratigraphic Relationships

The contact of the Birdhead with the underlying Lower Thermopolis Shale Member is sharp at some localities, gradational at others. At the type locality and in the Pryor Creek Valley area northwest of the thesis area, the basal part of the Birdhead is in abrupt planar contact with the underlying shale (Figure 21). The dark gray shale below the Birdhead contains bentonite and minor amounts of sand. These yellowish gray bentonitic and sandy zones form thin layers less than one inch thick which are interbedded with darker shale layers of the same thickness. Near the contact the

FIGURE 21. Birdhead Sandstone (Kbh) outcrop on Pryor Creek displaying sharp, planar, basal contact with the Lower Thermopolis Shale Member (Klt).

shale becomes more mixed and the sandy, bentonitic material is incorporated as streaks and stringers in the shale (Figure 22). The basal contact in the thesis area also is sharp except on the eastern side of Woody Divide where the basal three feet of the Birdhead consist of highly bentonitic, clayey sandstone. This unit is poorly bedded and contains material of clay-size up to sand-size quartz and volcanic rock fragments. Both montmorillonite clays and non-expandable clays are present as matrix material. Although the contact in this area appears transitional, the bentonitic shales below the contact contain very little sand-size material.

The contact of the Birdhead with the overlying Upper Thermopolis Shale Member is sharp at most localities except on the southern and eastern sides of Woody Divide. The upper four feet of the Birdhead at these two localities consist of poorly-bedded, bentonitic sandstone containing gray and black clay stringers and shale clasts. Here the upper part of the Birdhead represents a mixing of slightly lithified shale fragments and unconsolidated mud with sand. The contact is gradational but is readily located because the overlying shale is darker in color, well-bedded, and contains very little sand.

FIGURE 22. The Birdhead Sandstone (Kbh) in sharp contact with the underlying Lower Thermopolis Shale Member (Klt). The black shale below the Birdhead contains stringers and streaks of light-colored sandy bentonite.

Thickness and Lateral Persistence

The thinnest outcrop of Birdhead Sandstone found is located at the mouth of Birdhead Coulee near the type section (Figure 23). At this locality a thickness of approximately six feet was measured. Nearly four miles southeast of the type locality a thickness of 19 feet was recorded which is the maximum thickness of Birdhead found. Within the thesis area the Birdhead ranges in thickness from ten to 16 feet with an average of about 14 feet.

The Birdhead Sandstone generally thickens to the southwest and southeast from the type locality. Local variations in thickness appear to have been controlled by the slightly irregular bottom topography during deposition and by reworking and local erosion of the upper part of the unit.

The Birdhead Sandstone is a laterally persistent unit. The outcrop was traced almost continuously from 12 miles west of the thesis area, northwest to the type locality in Pryor Creek Valley, and southeast into the thesis area. Knappen and Moulton (34) mapped the Birdhead in the area west of the town of Pryor and traced it westward around the Pryor Mountains and almost to the Montana-Wyoming border. Because the Birdhead is a thin unit, it is commonly covered by debris from the overlying shales; however, the sandstone can usually be found where creeks or coulees cut back into the slumped areas.

FIGURE 23. The Birdhead Sandstone near the type locality in Birdhead Coulee. Only the upper four feet are exposed in the ledge; the basal contact is covered.

The lateral persistence and relatively uniform thickness of the Birdhead Sandstone suggest that this sand body is a sheet sand. The contacts are generally sharp and only locally are they gradational. The sandstones are cross-bedded to cross-laminated, contain ripple marks and scour-and-fill structures, are fine-grained, and include clay pebbles. Marine fossils mixed with terrestrial fossils including plant material are present in the Birdhead. These general characteristics of the Birdhead Sandstone are nearly identical to those postulated by Potter (52) in his definition of sheet sands.

Lithology

The outcrops of the Birdhead Sandstone can be divided into two general types. Northwest of the thesis area and in Pryor Creek valley the Birdhead forms an unbroken, steep-faced rim or ledge (Figure 24). In the mapped area the outcrops of the Birdhead are nonresistant and generally poorly defined (Figure 25). The main difference between the outcrop types is attributed to the types of cement present and the relative amounts of bentonite and other matrix material.

The reference section is characteristic of the ledge-forming outcrops (Figure 26). This section can be divided into four units.

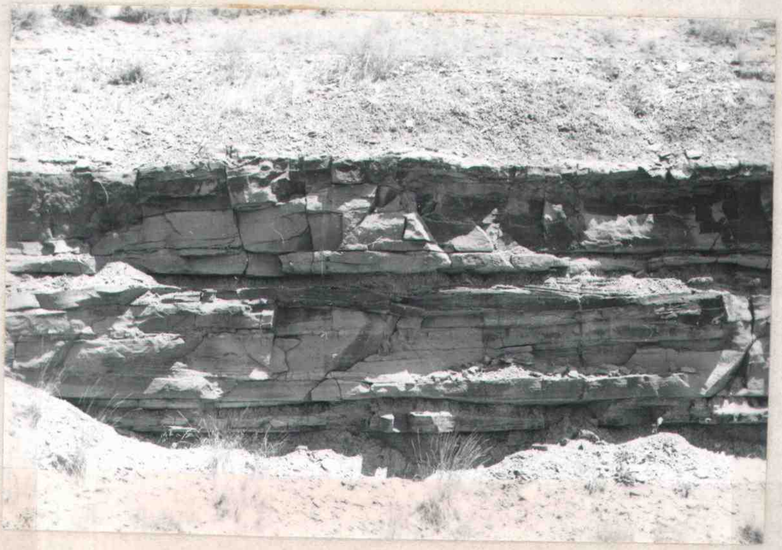


FIGURE 24. The resistant, steep-faced type of outcrop formed by the Birdhead Sandstone just north of the reference section on Pryor Creek. Note cross-bedding and -lamination.

FIGURE 25. The nonresistant type of outcrop formed by the Birdhead Sandstone in the central part of the thesis area on Hay Creek.

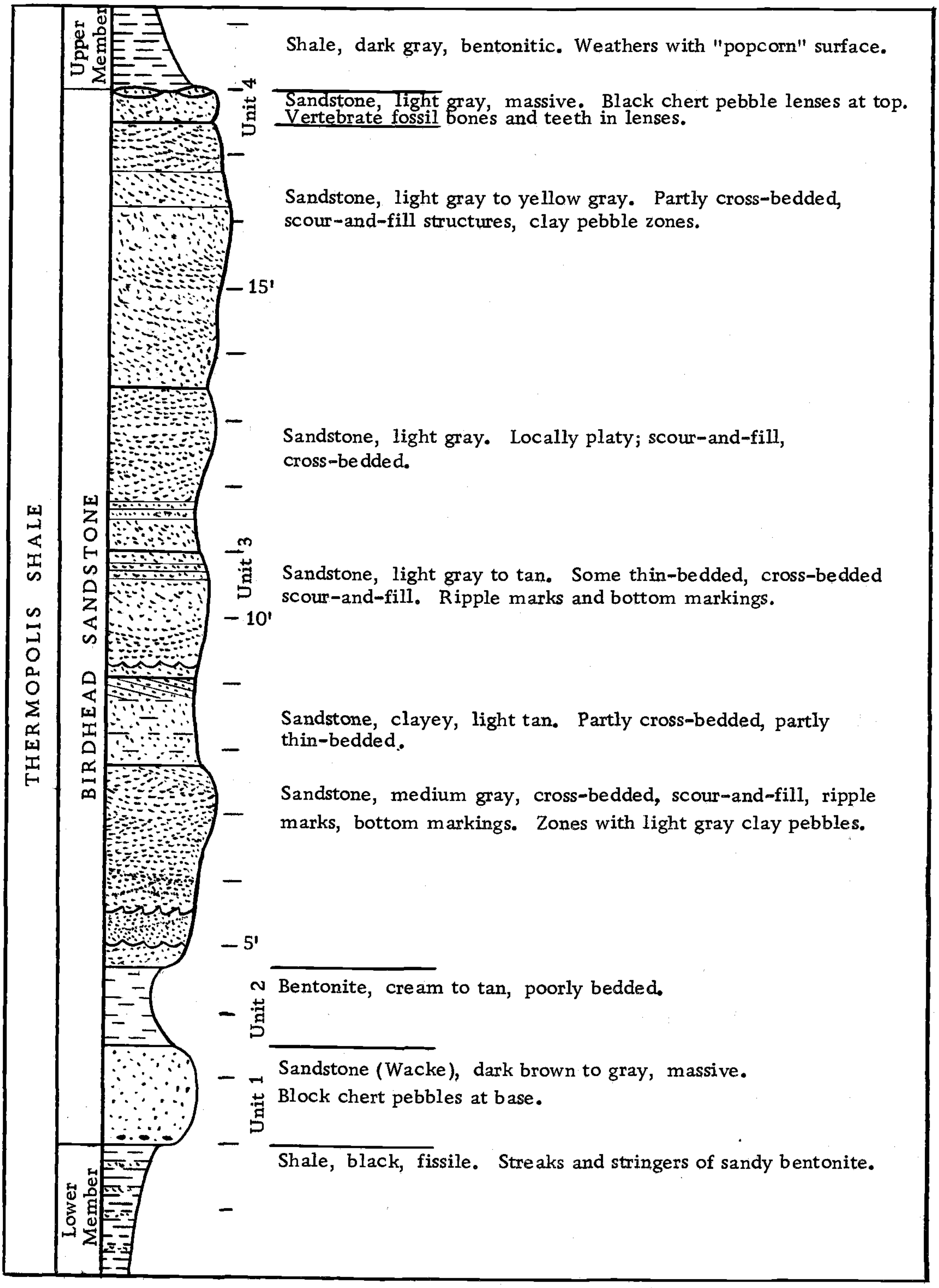


Figure 26. Proposed Reference Section: Birdhead Sandstone
center W 1/2, sec. 29, T. 3 S., R. 27 E., Yellowstone Co., Montana

The lowest unit is in sharp contact with the underlying shales of the Lower Thermopolis Shale Member and is a dark gray sub-feldspathic lithic wacke. The clay matrix appears to have been incorporated with the sand during the initial stage of sand deposition. The currents carrying the sand picked up mud, possibly from the unconsolidated depositional surface. This basal sandstone is massive and lacks the scour-and-fill structures and light color typical of most of the Birdhead. The thickness of this unit ranges from a few inches to nearly two feet. This basal sandstone is not present at the type locality or on the west side of Pryor Creek. It can, however, be traced east and south from the reference section into the thesis area where it is present at two localities in the northern part.

Overlying the basal sandstone is a cream to light gray bentonite bed which is in sharp contact with both the overlying and underlying units. This bentonite is not found at all localities but appears to occur in lenses ranging in thickness from a few inches to two feet. It may once have been a continuous deposit which was partly removed prior to the deposition of the overlying unit. Several localities in the thesis area have sandy, bentonitic zones near the base which may be correlative to the bentonite layer of the reference section.

The unit overlying the bentonite at the reference section varies greatly in lithology and thickness. It generally consists of light gray to yellow-gray fine-grained sandstone with a salt-and-pepper appearance and ranges in thickness from four to nearly 15 feet. The sandstones are not well-bedded but consist of a complex of shallow channels, lenses, and cut-and-fill zones (Figure 27). No single unit can be traced laterally for any significant distance, but this zone is everywhere present north and west of the thesis area. The sedimentary structures consists of current, oscillation, and interference ripple marks, scour-and-fill structures, cross-bedding and -lamination of the trough type, bottom markings and "worm trails", and rare mudcracks (Figures 28, 29, 30, 31). Also common to this unit are abundant clay pebbles (Figure 32). Several localities display irregular light gray clay inclusions which may have been formed by burrowing organisms (Figure 33).

The uppermost unit in the reference section consists of conglomeratic or pebbly sandstone lenses. The lenses are rarely over three feet in width and are less than a foot thick. Included in the lenses are vertebrate fossil remains. The fossils collected by the writer from the pebbly lenses were identified by Dr. J. H. Ostrom (45) as:

FIGURE 27. A channel in the upper part of the Birdhead Sandstone. The sandstones below the channel are cross-bedded and -laminated and display scour-and-fill structures.

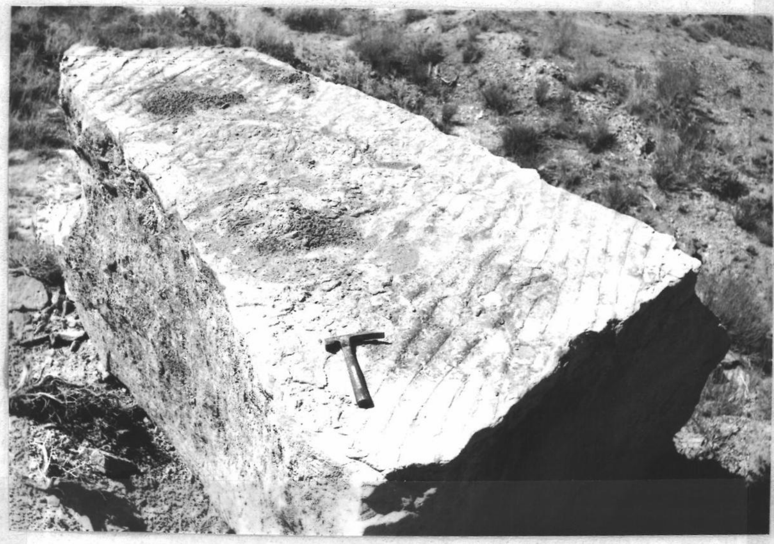


FIGURE 28. Current ripple marks in the Birdhead Sandstone. Near reference section on Pryor Creek.

FIGURE 29. Cross-bedding, cross-lamination, and ripple marks in unit of Birdhead Sandstone overlying a bentonite layer.

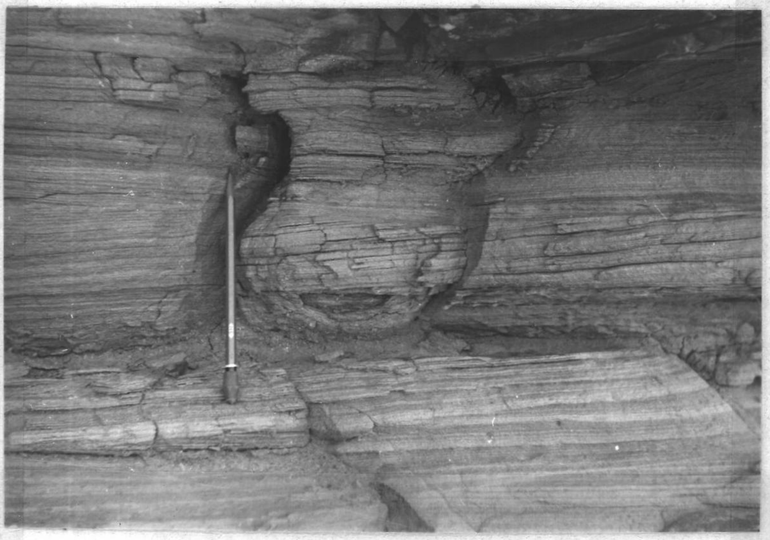


FIGURE 30. Cross-lamination in the Birdhead Sandstone. The pencil (six inches long) provides a scale.

FIGURE 31. "Worm trails" or bottom markings in the Birdhead Sandstone on Pryor Creek.

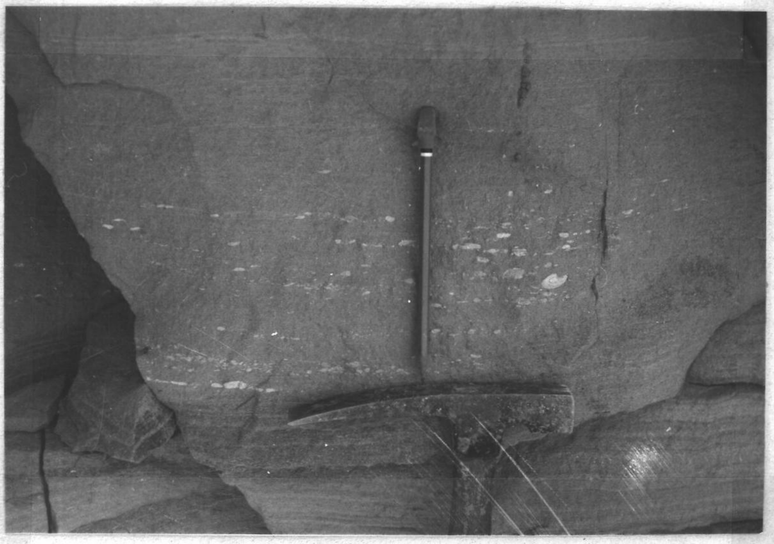


FIGURE 32. Clay pebble zone in laminated Birdhead Sandstone. The clay pebbles are aligned along bedding planes. Pencil is six inches long.

FIGURE 33. Clay inclusion in laminated Birdhead Sandstone possibly formed by a burrowing organism.

Shark teeth and spines:	Synechodus sp.
Holostean fish vertebrae and scales:	Lepisosteus (or Lepidosteus) sp.
Turtle plastron:	Glytops sp.
Crocodile teeth:	Species indeterminate

Included in the lenses are small pebbles of black and gray chert up to three millimeters in diameter and clay pebbles up to five millimeters in diameter. The chert pebbles are moderately rounded and slightly polished. The sand-sized fraction is similar to that found in the unit below the lenses. The contact with the overlying Upper Thermopolis Shale Member is sharp but gently undulating. The zone of lenses is found at nearly all localities where the Birdhead forms a resistant ledge.

The nonresistant type of outcrop is not easily divided into traceable units. At a few localities in the mapped area, one or more of the units described in the reference section are present. The dominant rocks of the nonresistant sections are soft, yellow-gray to light gray bentonitic sandstones interbedded with thinner, carbonate-cemented, light gray, cross-bedded and cross-laminated sandstones (Figure 34). Carbonaceous matter or plant debris is common in the bentonitic sandstones. The upper contact is sharp at some localities, gradational at others. Where the contact is abrupt the section is commonly capped by a thin, cross-laminated, light gray sandstone or by conglomerate lenses. A soft, medium

FIGURE 34. Birdhead Sandstone outcrop in the central part of the the thesis area on East Fork of Pryor Creek. This outcrop shows typical interbedded soft bentonitic sandstones and thin cross-laminated calcareous sandstones.

gray, bentonitic sandstone, locally including black shale clasts, composes the upper unit where the contact is gradational.

The section measured in sec. 26, T. 4 S., R. 28 E. on the east side of Woody Divide consists of three units. The basal unit is a medium gray, poorly sorted sandstone which included black shale stringers and clasts. This three-foot unit contains grains of angular quartz and volcanic rock fragments up to one millimeter in diameter. This unit appears to be a product of currents which ripped up poorly consolidated shale, mixed the shale clasts with sand, and deposited the mixture rapidly without later reworking. The middle unit consists of six feet of laminated soft, gray, bentonitic sandstone with a few zones of well-cemented, cross-laminated sandstones less than one foot thick. The upper unit resembles the basal unit but does not contain the coarse quartz grains and rock fragments. This upper sequence is four feet thick, contains appreciable amounts of bentonite, and has thin (less than 1/2 inch) black shale partings at several intervals.

Petrographic Analysis

Twenty sections of the Birdhead Sandstone were measured in the thesis area and in adjacent areas north and west. Samples were collected from all measured sections. Most of the rocks are generally well-cemented; however, several samples had to be impregnated before thin sections could be made. The rocks with a high bentonite content were not sectioned; instead grain mounts were made. No significant differences in the sand fraction were found between the grain mounts and the thin sections.

The Birdhead Sandstone is generally very fine- to fine-grained, and sorting ranges from moderate to poor. In some examples the poor sorting is the result of the clay or bentonite matrix; in others of the inclusion of random coarse grains. The larger grains range from angular to rounded: quartz is generally subrounded to rounded, feldspars are angular to subrounded, and volcanic rock fragments are commonly subrounded. Of the rocks examined in thin section, none were found to have significant porosity.

The mineralogical composition of the Birdhead is relatively constant in all areas examined by the writer. The individual detrital components vary only in relative abundance between outcrops. The major detrital components found in the Birdhead are quartz, chert, plagioclase, and volcanic and metamorphic rock fragments. The light and heavy fractions are listed in Table 2.

Table 2. Birdhead Sandstone Detrital Components

Light Minerals	Heavy Minerals
quartz	zircon
chert	tourmaline
plagioclase (An_{29}-An_{48})	apatite
orthoclase	rutile
microcline	garnet
glauconite	biotite (green and brown)
clays (undifferentiated)	ilmenite
	sphene ?
	chlorite

Rock Fragments

chert
volcanic rock fragments (dark)
metamorphic rock fragments

The Birdhead Sandstone is generally composed of quartz and chert (70-80%), andesine, orthoclase, and microcline (5-15%), and dark volcanic and metamorphic rock fragments (10-25%). Biotite is common to all of the rocks, and exceptionally forms up to five percent of the rock. The most common heavy minerals are zircon, tourmaline, rutile, and biotite, but they generally comprise less than three percent of the rock.

The bonding materials in the Birdhead are of three main types. Calcite with small patches of microcrystalline quartz and quartz overgrowths with interstitial hematite and limonite as authigenic cements compose the first type. The second type of bonding material is detrital, nonexpanding clay. These two types of bonding materials are most common in the resistant type outcrops. Bentonite as a matrix is the third type of bonding material. This last type, with lesser amounts of calcite cement, is common in the nonresistant type outcrops.

The sandstones examined in thin section are classified according to Gilbert (68). The rocks containing bentonite and other clays as matrix range from subfeldspathic to feldspathic lithic wackes. The rocks cemented by calcite are calcareous subfeldspathic to feldspathic lithic arenites, and those cemented by quartz, hematite, and limonite are generally feldspathic lithic arenites. The matrix or cement appears to be the main variable in the Birdhead. The detrital minerals vary only in relative abundance indicating that all of the sandstones in the Birdhead were derived from a common source.

Three main sources are indicated by the mineralogy and detrital components of the Birdhead Sandstone. First, some quartz grains are rounded and a few display worn overgrowths. The quartz, together with chert and a relatively stable heavy mineral suite, probably were derived from older quartzose sandstones and cherty limestones. Small amounts of orthoclase and microcline may indicate that some of the source sandstones were arkosic. Second, the andesitic plagioclase, some examples of which are zoned, the biotite, and the volcanic rock fragments indicate volcanic rocks in the source area. The high bentonite content indicates that the volcanism was active at the time of erosion of the source area. Finally, a metamorphic terrane contributed to the Birdhead as indicated by phyllitic and schistose rock fragments.

The detrital components found in the Birdhead are nearly identical to those described in the Muddy Sandstone in the Big Horn Basin by Paull (46). Paull suggested a western source area for the Muddy Sandstone. He postulated quartzose sandstones and cherty limestones in the area of the Idaho Batholith as the sources for the Muddy in the Big Horn Basin. The source of the Birdhead Sandstone appears to be similar to that of the Muddy Sandstone. MacKenzie and Poole (41) reported that volcanism occurred in the Early Cretaceous in the area west and northwest of Wyoming. The volcanics are postulated as the source of volcanic rock fragments, biotite, and bentonite found in the Birdhead. The metamorphic rock fragments may have been derived from metamorphic rocks in the Idaho area or even from farther north in Canada.

Depositional Environment

The environment of deposition for the Birdhead Sandstone in the area of study is nearshore - marginal deltaic. The postulation of this environment is based on the sedimentary structures, fossils, and facies relationships found in the Birdhead. The marginal deltaic environment is subdivided into a shallow water, relatively high energy facies and a slightly deeper facies which was deposited below wave base.

In the area of study the Birdhead is divided into two facies based on sorting and sedimentary structures. Cross-bedding and -lamination, current, oscillation, and interference ripple marks, scour-and-fill structures, and mudcracks are found in the Birdhead. These features, together with rounded chert pebbles in the upper part of the Birdhead, indicate a shallow water environment which was strongly affected by current and/or wave action. These current features are best displayed in the sections in Pryor Creek valley and north of the mapped area. The sandstones in this area are generally moderately to well-sorted. The Birdhead Sandstone in this area represents the shallow water, high energy facies.

The second facies is represented by the sandstones found in the thesis area. This facies is characterized by laminated bentonitic sandstones interbedded with thinner, cross-bedded and -laminated sandstones. This interbedded sequence is indicative of current alternating with quiet water deposition. This episodic current deposition may have been the result of flooding or storms rather than tidal or seasonal variations because the occurrence of the two types of deposits is irregular rather than alternating or cyclic. The Birdhead Sandstone in the thesis area represents the deeper water facies. The dominance of laminated, poorly sorted sandstones indicates that this facies was deposited below wave base and was only occasionally affected by wave or current activity.

Plant debris and the vertebrate fossil assemblage indicate that the Birdhead was deposited in a nearshore zone ranging from shallow marine to brackish water. Dr. J. H. Ostrom (45) reported that the fossil assemblage found in the Birdhead lived in a shallow marine environment not too distant from the shore line. He stated that the turtle remains represent a terrestrial form, and that the hybodont sharks were mainly marine. Dr. Ostrom identified the fish remains as those of a gar pike type which are occasionally found in either marine or brackish water. The fossil assemblage in the Birdhead Sandstone represents a mixing of terrestrial, brackish, and marine environments which indicates that the Birdhead was probably deposited in a nearshore zone. The terrestrial fossils were washed into the nearshore environment and deposited with the brackish and marine forms.

Investigations of the Birdhead Sandstone in adjacent areas support a conclusion that the environment of deposition in the area of study was intermediate between a fluvial deltaic facies and a neritic facies. Knappen and Moulton (34) reported that the Birdhead Sandstone north and west of the Pryor Mountains occurs in 30-foot deep, steep-sided channels overlain by thin sandstone layers which connect the channel deposits. They suggested that the Birdhead in this area was deposited by large streams that meandered over a barely submerged mud flat. The fluvial-deltaic facies reported by Knappen and Moulton is located west of the shallow water, marginal deltaic facies described by the writer.

Thom *et al.* (63) stated that the Birdhead becomes less prominent to the east in the Crow Indian Reservation and disappears except for a few thin sandstone lenses at Soap Creek, about 20 miles east of the thesis area. The Birdhead described by Thom *et al.* is interpreted by the writer to represent a neritic facies located east of the marginal deltaic facies in the thesis area.

Conclusions

The suggested environments and general character of the Birdhead Sandstone in areas east and west of the thesis area indicate that the environment of deposition for the Birdhead in the area of study was intermediate between a fluvial-deltaic facies and a neritic facies. The character of the Birdhead in the thesis area and in Pryor Creek valley indicates that the specific environment of deposition was marginal deltaic.

The suggested source area for the Birdhead Sandstone was to the west. The lateral stratigraphic relationships suggest that a river complex carried clastic material from a positive area to the west and deposited the material in a shallow sea. No delta features such as channels, interdistributary deposits, or bar sands could be recognized in the Birdhead within the area of study. Therefore, it is assumed that the environment of deposition in the mapped area and in the area immediately north was marginal to a delta which formed farther west.

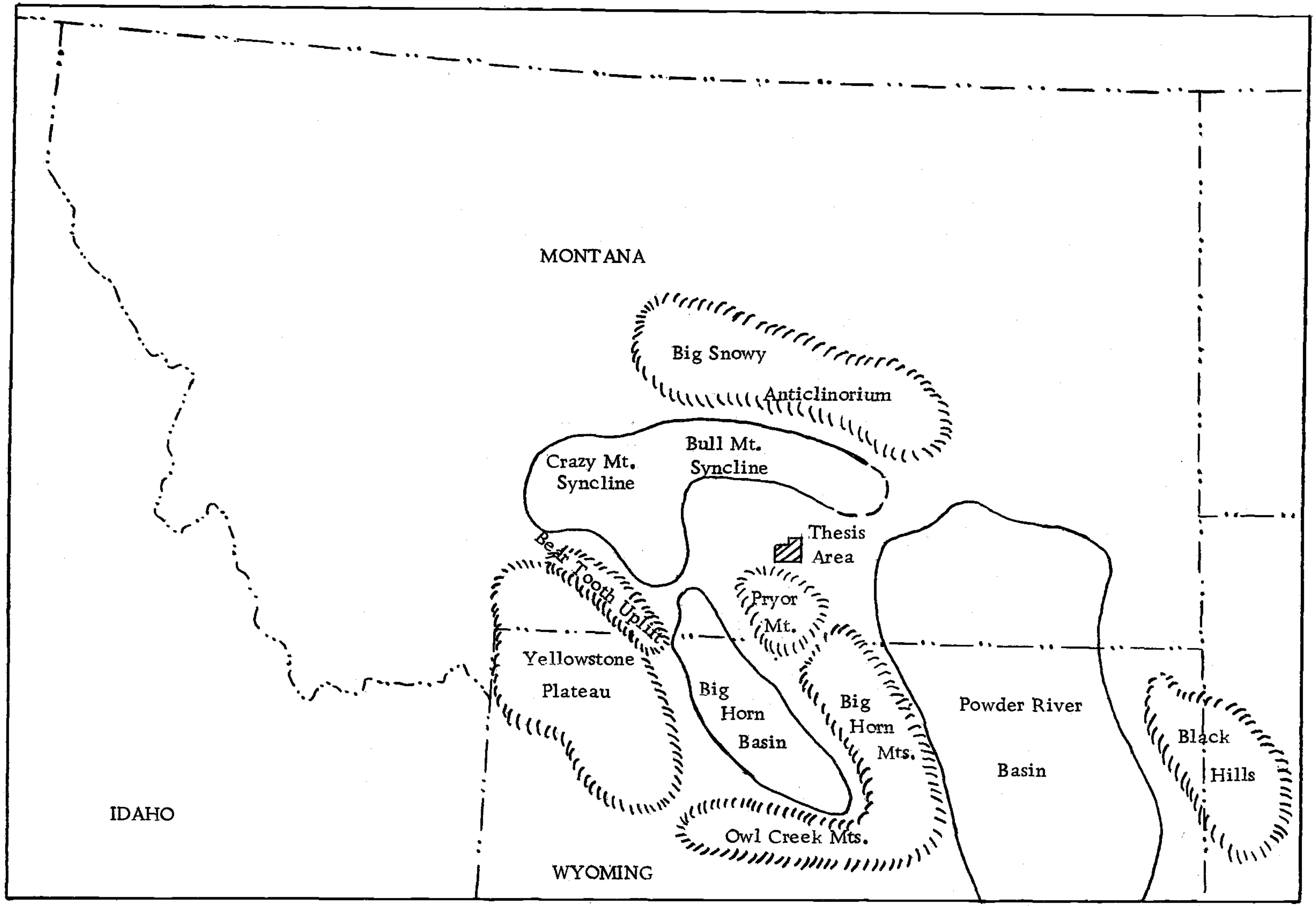
The mineral assemblage in the Birdhead is nearly identical to the assemblage in the Muddy Sandstone of the Big Horn Basin as described by Paull (46). Both Paull and Chisholm (10) reported that the source of the Muddy Sandstone was to the west and northwest of Wyoming. Gries (25) and MacKenzie and Poole (41) reported that the Newcastle Sandstone of the Powder River Basin was derived from an eastern source. The Birdhead Sandstone in considered to be marginal to a deltaic complex that lies to the west rather than being related to the Newcastle delta to the east.

STRUCTURAL GEOLOGY

The area of study is located in the northern Great Plains region. In this region there is a series of isolated mountain ranges separated by extensive plains and/or structural basins. These ranges are commonly referred to as being part of the northern Rocky Mountains but their history and formation differs from the actual northern extension of the Rocky Mountains in western Montana. Perry (50) refers to the isolated mountains of Montana as the "plains mountains".

Regional Structure

The structural pattern in south-central Montana and northern Wyoming is dominated by a system of structural basins separated by mountain arches (Plate 2). In northeastern Wyoming and southeastern Montana the major structural feature is the Powder River Basin. West of the Powder River Basin the Big Horn Mountains form a northwest-southeast trending arch which extends from southern Montana into central Wyoming. The Pryor Mountain complex in south-central Montana is separated from the northern Big Horn Mountains by the Big Horn Canyon. The Pryor Mountains in combination with the Big Horn Mountains separate the Powder River Basin on the east from the Big Horn Basin on the west.



(after E. A. Riggs, 1960)

Plate 2. Major basins and uplifts of Northern Wyoming and Southern Montana.

North of the Pryor Mountains the strata dip regionally northward in a homoclinal sequence which locally is interrupted by small faults, domes, anticlines, and synclines. The Lake Basin-Huntley fault zone, a northwest-southwest trending system of _en echelon_ faults, forms the northern border of the homocline (2).

Thom (62) divided the deformational history of the Big Horn Mountains and adjacent areas into seven major phases. The first phase was the development of rifts and fault blocks in the crystalline basement during the Precambrian. The next phase was the erosion and planation of the crystalline basement during a stage of crustal stability. Phase three was the development of a geosyncline to the west and a shallow shelf to the east with minor adjustments on the Precambrian rifts. This phase occurred during the interval from the Precambrian to the Permian. The fourth phase, during the Mesazoic, was characterized by the introduction of volcanics from the west in association with the first pulses of the Laramide Orogeny. In the interval from Jurassic to Cretaceous the Laramide disturbance migrated east until a culmination in the early Tertiary. During this interval the Colorado Front Range and the structural basins and ranges in the northern Great Plains were formed. The final three phases involved structural readjustments, uplift, and volcanism. Thom did not associate major structural features with these last three phases.

Blackstone (4) presented a detailed description of the Pryor Mountains including their history and the structural mechanics involved in their formation. He reported that the faulting in the Pryor Mountains was a reflection in the sedimentary cover of Laramide movements on the "blocked" zones of weakness in the Precambrian basement. The Pryor Mountains consist of four major tilted blocks with several minor blocks. The northeast corners of the blocks have been uplifted to form asymmetrical anticlines. The steeper flanks of the asymmetrical anticlines can be traced laterally into ruptured folds bordered by faults. Blackstone described the border faults as curved reverse faults which appear as high angle normal faults at the surface.

Thesis Area Structure

The structures in the thesis area are related to the formation of the Pryor Mountains complex and to minor flexures in the homocline north of the Pryors. The northeasternmost part of the Pryor Mountains is included in the southwestern corner of the mapped area. The gently north-dipping strata in the northern two-thirds of the area are part of the homocline.

Folds

Woody Divide Syncline

The escarpment which forms Woody Divide in the central part of T. 4 S., R. 28 E., is capped by the Mowry Shale. This north-south trending divide lies on the axial trace of the Woody Divide Syncline which plunges north. The flank dips of the syncline range from two to five degrees and are difficult to determine in the field; most were estimated from aerial photographs.

Beauvais Creek Monocline

The headwaters of Beauvais Creek in the south-central and south-eastern parts of the area cut through a series of north-dipping cuestas formed in the Chugwater, Sundance, and Morrison Formations and the Cloverly Group. The strata of these formations rise from the north-dipping homocline to maximum dips of 20 degrees before flattening again south of the mapped area.

Shively Hill Dome

The Shively Hill Dome in the south-central part of T. 5 S., R. 27 E., was formed as part of the Pryor Mountains Uplift. It lies at the eastern end of Castle Butte Fault and is asymmetrical to the northeast (Figure 35). The dips on the north and east flanks range from ten to 65 degrees as contrasted to the five to nine-degree dips on the south and west flanks. The interior of the dome is covered by the Embar Limestone and the Tensleep Sandstone. East Fork of Pryor Creek has cut a deep north-south canyon in the eastern part of the dome. The upper Madison Limestone and the Amsden Formation are exposed in the walls of the canyon. Castle Butte Fault truncates the northwest corner of the dome where the Tensleep Sandstone lies against ridges of Chugwater, Sundance, and Cloverly (Figure 36).

North Pryor Mountain

North Pryor Mountain lies in the extreme southwestern corner of the thesis area in secs. 29-32, T. 5 S., R. 27 E. This mountain is the northeastern corner of Northeast Pryor Block as described by Blackstone (4). The Madison Limestone forms the upper surface of the mountain and then dips steeply into the asymmetrical synclinal valley of Hay Creek. South of the thesis area the asymmetrical North Pryor Mountain anticline is broken by a fault. The north end of North Pryor Mountain is truncated by Castle Butte Fault.

FIGURE 35. Looking southeast toward Shively Hill Dome. The Chugwater hogback to the left is dipping north at approximately 40 degrees. The Chugwater cuesta on the right is dipping about 10 degrees to the southwest. The Embar Limestone forms the grasslands in the center of the dome, and the Tensleep Sandstone crops out in the tree-covered canyons and coulees.

FIGURE 36. Castle Butte Fault cutting the northeast flank of Shively Hill Dome. The tree- and brush-covered ridge on the left is formed on the Tensleep Sandstone (Pennsylvanian). The grass-covered ridge on the right is formed on the Pryor Conglomerate (Early Cretaceous) and the Morrison Formation (Late Jurassic).

Faults

Castle Butte Fault

The north end of the Pryor Mountains is truncated by Castle Butte Fault which is reported by Thom _et al._ (63) to be nearly 14 miles long. The maximum stratigraphic separation on this east-west trending fault is nearly 2, 000 feet where the Madison Limestone rests against Thermopolis Shale. Blackstone (4) described this fault as a high-angle, curved reverse fault which appears to be a normal or vertical fault at the surface. Castle Butte Fault cuts the north flank of North Pryor Mountain in the thesis area and continues eastward across Hay Creek. The fault truncates the northeast corner of Shively Hill Dome and appears to die out in the north flank of the dome.

Faults in the Southern Part of the Thesis Area

In secs. 31-36, T. 5 S., R. 28 E., of the mapped area, two east-west trending vertical faults cut the Beauvais Creek Monocline (Plate 3). In a small valley in sec. 32, T. 5 S., R. 28 E. the western fault dies in the Embar and Tensleep Sandstone. The northern upthrown side has a maximum displacement of approximately 50 feet. The eastern fault is not well-defined in the field but is easily seen on aerial photographs. The south side of this fault is the upthrown side, but the stratigraphic separation in the lower Sundance Formation is only a few feet.

GEOLOGIC HISTORY

Paleozoic Era

Sloss (61) presented a simplified regional discussion of sedimentation during the Paleozoic Era in Montana and adjacent areas. He divided the tectonic framework into a basin located in the present site of the Williston Basin, a north-south trending geosyncline in western Montana and in Idaho, and the Central Montana Trough which appears to have been the main connection between the geosyncline and the Williston Basin. South of the Central Montana Trough the relatively stable Wyoming Shelf existed during the Paleozoic Era. Sloss (61) reported that the Lake Basin-Huntley Fault zone forms the northern border of the Wyoming Shelf. The thesis area lies only a few miles south of this fault zone thus placing the mapped area on the Wyoming Shelf near the hinge line between the Central Montana Trough and the shelf. The Paleozoic rocks generally indicate that a stable shelf environment was present in the thesis area during the Paleozoic Era.

The Mississippian Madison Limestone is the oldest formation exposed in the mapped area. The limestones of the Madison are characteristic of shallow, warm, sea deposits found on stable shelves. At the close of the Osagean Epoch the stable shelf area in south-central Montana was uplifted and an extensive erosional topography was developed. The karst topography of the upper Madison is well-displayed in the mapped area. The Central Montana Trough continued to receive the sediments of the Big Snowy Group during the Osage.

The close of the Mississippian Period brought renewed marine submergence with the deposition of the limestones in the lower Amsden Formation. The shallow marine conditions of the Late Mississippian continued into the Pennsylvanian but limestone deposition was transitionally replaced by the deposition of the clean quartzose sandstones of the Tensleep Sandstone. This lithology change may reflect the presence of local positive areas on the shelf which permitted the formation of dune and beach deposits.

The conditions controlling the deposition of the Embar Limestone are not clear but this Permian Limestone probably indicates marine deposition. This marine environment may have existed into the Triassic.

Mesozoic Era

The environments of deposition of the Chugwater red beds sequence are not fully understood but marine fossils, found in the thin limestones, indicate that marine conditions existed during part of the Triassic. The gypsum deposits indicate that restricted or evaporitic conditions prevailed during part of Chugwater deposition.

The Triassic rocks were eroded in Late Triassic to Early Jurassic time. The Chugwater was completely removed north of the Lake Basin-Huntley Fault in central Montana. This erosional surface then was transgressed by the Middle Jurassic Sundance Sea. The Sundance Formation was deposited in a shallow sea much affected by wave and current action. During Late Jurassic time the Sundance sea slowly regressed to the north.

No break in sedimentation can be detected between the marine Sundance Formation and the continental rocks of the Late Jurassic Morrison Formation. The sea remained withdrawn from the area for the remainder of the Jurassic and into the Cretaceous Period.

The fluvial conglomerates and sandstones of the Early Cretaceous Pryor Conglomerate represent one of the first Laramide pulses. An uplifted source area and associated volcanism to the west contributed much of the material for the Pryor Conglomerate. The Pryor Conglomerate and the overlying Fuson Shale consist of continental sandstones and bentonitic claystones. The "Rusty Beds" at the top of the Cloverly Group represents the gradual transgression of the Thermopolis sea which covered much of the northern Great Plains.

The Lower Thermopolis Shale was deposited in a shallow marine environment which received very little coarse clastic material. The Birdhead Sandstone Member of the Thermopolis represents a renewed uplift in the western source area. This shallow marine sandstone was derived from the west through a fluvial and deltaic complex probably similar to the Newcastle delta of the Black Hills region. The abundance of bentonite and volcanic rock fragments in the Birdhead indicates that increased volcanism accompanied the uplift in the source area. The vertebrate fossil assemblage found in the Birdhead is nearly identical to the assemblage in the Upper Thermopolis Shale. This fact suggests that the environment of deposition changed little during the deposition of the two units. It also suggests that the Birdhead Sandstone may represent infilling of the shallow Thermopolis sea rather than extensive regression through uplift of the sea floor. Contemporaneous with the formation of the Birdhead the Muddy Sandstone, the Newcastle Sandstone, and correlative sandstones in Colorado were deposited. The presence of these sandstones in nearly the same stratigraphic position over an extensive area suggests that western and eastern uplifted areas were contributing fluvial and deltaic sediments up and down the Laramide orogenic belt.

The faunal assemblage of the Upper Thermopolis Shale is reported by Eicher (22) to be a mixture of Gulf and Arctic forms. Although the contact between the Thermopolis and the overlying Mowry shale is transitional, the Mowry faunal assemblage is entirely Arctic as reported by Wulf (72). The change in faunal affinities indicates that the connection with the Gulf was no longer present and that Arctic waters from the north covered the area up to the end of the Early Cretaceous.

The rocks deposited in the Late Cretaceous and Tertiary have been stripped from the thesis area by erosion. These rocks in adjacent areas reflect the increasing activity of the Laramide Orogeny in the northern Rocky Mountains and northern Great Plains. The Laramide deformation reached a climax in the Eocene but continued with decreasing activity into the Oligocene (4). During the Laramide disturbance the Big Horn Mountains were repeatedly uplifted and sediments, continuously shed from the positive areas, filled the adjacent basins.

At present the south-central Montana region is being extensively eroded by the drainage systems of the Big Horn and Yellowstone Rivers. Thom *et al.* (63) suggested that these drainage systems were established during the later uplifts of the Big Horns.

GEOMORPHOLOGY

Topographic Features

Woody Divide

The divide in the northeastern part of the thesis area between the Pryor Creek drainage system and the Beauvais Creek drainage system is locally called Woody Divide (Plate 3). It is a long north-south trending bench which narrows to the south. Woody Divide, which is developed on a gently north-plunging syncline, is capped by the resistant, siliceous Mowry Shale (Cretaceous).

The west side of the bench is moderately steep and is deeply dissected by the tributaries of East Fork Pryor Creek. The east side is steeper than the west side and forms a long, straight cliff which is marked by large-scale slumping and associated sag ponds. Around Woody Divide shale badlands lie immediately below the steep slopes. The north-flowing North Fork Woody Creek cuts a deep canyon into the center of the divide.

Beauvais Creek Cuestas

South of Woody Divide, in the southern part of the area, the topography consists of a series of north-sloping cuestas. These cuestas are held up by the more resistant sandstones and limestones in the Triassic, Jurassic, and lowermost Cretaceous formations. The cuesta scarps trend east-west and extend from the eastern boundary of the area west to the north flank of Shively Hill Dome (Plate 3). Subsequent strike valleys have been cut in the less resistant shales, and the cuestas are cut transversely by the headward erosion of tributaries to Beauvais Creek. As a consequence, a crude trellis-like drainage pattern has been developed.

Shively Hill Dome

Shively Hill Dome is both a structural and topographic dome which lies in the south-central part of the thesis area (Plate 3). The hogbacks on the north flank pass into cuestas on the east and south flanks as the dip decreases. The central part of the dome is capped by the resistant Embar Limestone (Permian) which forms a smooth domal stripped structural surface. East Fork Pryor Creek occupies a steep-walled canyon cut into the west central part of the dome.

North Pryor Mountain

The highest (6, 800 feet) and most prominent topographic feature is North Pryor Mountain located in the southwest corner of the mapped area (Plate 3). This mountain consists mainly of thick

Mississippian limestones which are resistant to erosion. The smooth upper surface of the mountain slopes gently to the southwest. A few sink holes are present in this surface. The eastern flank is developed on the steeper limb of an asymmetrical anticline. Hay Creek Valley is developed on an asymmetrical syncline separating North Pryor Mountain from Shively Hill Dome. The north flank is truncated by Castle Butte Fault and is a resequent fault-line scarp.

Black Mountain

At the north end of Shively Hill Dome the interstream divide between Hay Creek and East Fork Pryor Creek rises nearly 400 feet above these creeks. The southern end of the divide is underlain by Upper Thermopolis Shale (Cretaceous). The local name given to this narrow hill is Black Mountain (Figure 37). The sides of the interstream divide are highly dissected by the tributaries of both creeks leaving an isolated, pointed, shale hill in the center.

Stripped Structural Plain

The topography of the northwestern quarter of the mapped area is developed on a gentle north-dipping homocline. The flat interstream divides are held up by thin resistant siltstones and

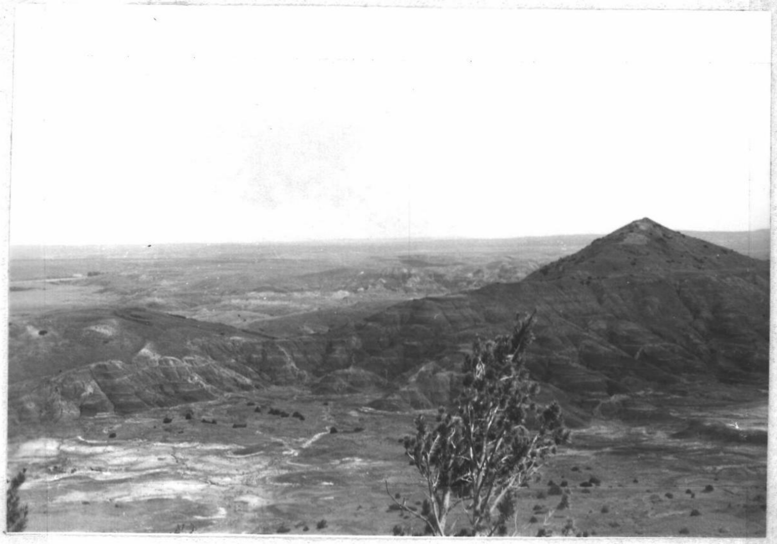


FIGURE 37. Black Mountain. This topographically prominent feature is formed by mass wasting in the Upper Thermopolis Shale Member.

sandstones in the Thermopolis Shale. The higher divides are held up by the Birdhead Sandstone. This area is essentially a stripped structural plain on these Cretaceous formations. Dissection of the more resistant cap rock has produced steep-walled valleys in the underlying soft shales. The creeks are north-flowing and appear to be resequent streams.

Floodplains

The floodplain deposits of the streams are all Recent alluvial deposits. No terraces have been formed. The valleys in the northern half of the thesis area are up to one mile wide and the floodplains are well-developed by the meandering streams. Most of the deposits are sands and gravels derived from the older formations to the south. Silts and clays, derived from the shale formations adjacent to the streams, are locally significant.

The main creeks in the northern half of the area are in a stage of maturity as shown by their meandering courses and the floodplains developed on at least one side of the valley. The streams in the southern half of the area are in late youth or early maturity inasmuch as the gradients are steeper and floodplains are less developed.

Landslides

A limestone landslide deposit covers the stream divide between the upper parts of Hay Creek and Deep Creek at the foot of the north flank of North Pryor Mountain. This is the only part of the mapped area which is covered by landsliding. The surface of this north-sloping divide is littered with limestone cobbles and boulders derived from the Amsden and Madison limestones on North Pryor Mountain. The deposit completely covers Castle Butte Fault and all outcrops as they cross the divide.

Slump Features

The valley walls of the streams in the northern half of the area are affected by minor slumping of the shale units. Slumping is the major erosional process by which the southern and eastern sides of Woody Divide are being reduced. The upper part of the steep scarps of the divide consist of resistant Mowry Shale which is being sapped by slumping of the softer underlying Thermopolis Shale. Large blocks of Mowry and Thermopolis Shale litter the slopes beneath the scarp and the slump blocks often cover the outcrop of the Birdhead Sandstone.

ECONOMIC GEOLOGY

Oil and Gas Possibilities

No stratigraphic or structural conditions favorable for the accumulation and entrapment of oil or gas were found in the thesis area. Shively Hill Dome presents the most favorable structural trap. However, the main reservoir rocks, the Tensleep Sandstone and the Madison Limestone, are exposed. No oil staining was found in either formation.

Facies changes in the Birdhead Sandstone present the only stratigraphic condition potentially favorable for oil accumulation. Offshore bars in the Birdhead, similar to those found marginal to deltaic deposits of the Muddy Sandstone in the Big Horn Basin, may be present in the subsurface east of the mapped area. However, to date such features have not been located either at outcrop or in the subsurface. No test holes have been drilled in the thesis area.

Bentonite Deposits

Knechtel and Patterson (35) have studied in detail the bentonite deposits in the Cretaceous formations of south-central Montana. They list four bentonite beds in the Thermopolis Shale which are suitable for industrial use, but they state that these deposits are not located in sites favorable for strip mining. The Mowry Shale in south-central Montana also contains many bentonite deposits. The most prominent deposit is the Clay Spur bentonite near the top of the formation. Knechtel and Patterson stated that this deposit also is not located in sites favorable for strip mining.

At present no bentonite deposits in south-central Montana are being mined. The bentonites may become economic in the future with increased demand and development of new mining techniques.

BIBLIOGRAPHY

1. Agatston, R. S. Pennsylvanian and Lower Permian of northern and eastern Wyoming. American Association of Petroleum Geologists, Bulletin 38:508-583. 1954.

2. Alpha, A. C. and J. P. Fanshawe. Tectonics of northern Big Horn Basin area and adjacent south-central Montana. Billings Geological Society, Guidebook 5:72-79. 1954.

3. Andrichuk, J. M. Mississippian Madison Group stratigraphy and sedimentation in Wyoming and southern Montana. American Association of Petroleum Geologists, Bulletin 39:2170-2210. 1955.

4. Blackstone, D. L. Structure of the Pryor Mountains, Montana. Journal of Geology 48:590-618. 1940.

5. Blackstone, D. L. and P. O. McGrew. New occurrence of Devonian rocks in north central Wyoming. Billings Geological Society, Guidebook 5:38-43. 1954.

6. Branson, C. C. Stratigraphy and fauna of the Sacajawea Formation, Mississippian, of Wyoming. Journal of Paleontology 11:650-660. 1937.

7. ________________. Pennsylvanian formations of central Wyoming. Geological Society of America, Bulletin 50:1199-1226. 1939.

8. Branson, E. B. Triassic-Jurassic 'Red Beds' of the Rocky Mountain region: a reply. Journal of Geology 37:64-75. 1929.

9. Brown, R. W. Fossil plants and Jurassic-Cretaceous boundary in Montana and Alberta. American Association of Petroleum Geologists, Bulletin 30:238-248. 1946.

10. Chisholm, W. A. The petrology of Upper Jurassic and Lower Cretaceous strata in the western interior. Wyoming Geological Association - Billings Geological Society, Guidebook 1:71-86. 1963.

11. Cobban, William A. and John B. Reeside, Jr. Correlation of the Cretaceous formations of the western interior of the United States. Geological Society of America, Bulletin 63:1011-1044. 1952.

12. Collier, A. J. and S. H. Cathcart. Possibility of finding oil in laccolithic domes south of the Little Rocky Mountains, Montana. U. S. Geological Survey, Bulletin 736 (Part II): 1-173. 1922.

13. Condit, D. D. Relations of the Embar and Chugwater Formations in central Wyoming. U. S. Geological Survey, Professional Paper 98:263-270. 1916.

14. Darton, N. H. Jurassic formations of the Black Hills of South Dakota. Geological Society of America, Bulletin 10:384-396. 1899.

15. ________________. Preliminary description of the geology and water resources of the southern half of the Black Hills and adjoining regions in South Dakota and Wyoming. In: Annual reports of the Department of the Interior; 21st annual report of the U. S. Geological Survey, Part 4, Hydrography. Washington, D. C., Government Printing Office, 1901. p. 489-599.

16. ________________. Comparison of the stratigraphy of the Black Hills, Big Horn Mountains, and Rocky Mountain Front Range. Geologic Society of America, Bulletin 15:379-448. 1904.

17. ________________. Geology of the Big Horn Mountains. U. S. Geological Survey, Professional Paper 51:1-129. 1906.

18. ________________. Geology of the Owl Creek Mountains with notes on resources of adjoining regions in the ceded portion of the Shoshone Indian Reservation, Wyoming. Washington, Government Printing Office, 1906. 48p. (Senate Document no. 219, 59th Congress, 1st Session)

19. Davis, J. C. Origin of the Mowry Shale. University of Wyoming Contributions to Geology 2:135-146. 1963.

20. Denson, M. E., Jr. and N. S. Morrisey. Subsurface correlations within the Madison Group, Big Horn and Windriver Basins. Billings Geological Society, Guidebook 5:44-49. 1954.

21. Doroshenko, J. Pre-Cambrian relationships of the Big Horn and Beartooth Mountains. Billings Geological Society, Guidebook 12:58-66. 1961.

22. Eicher, D. L. Biostratigraphy of the Thermopolis, Muddy and Shell Creek Formations. Wyoming Geological Association, Guidebook 17:72-93. 1962.

23. Emmons, Sammuel Franklin, Whitman Cross, and George Homans Eldridge. Geology of the Denver Basin in Colorado. U. S. Geological Survey, Monograph 27:1-556. 1896. (59th Congress, 2d Session, House of Representatives, Document no. 136)

24. Gardner, L. S. et al. Stratigraphic sections of Upper Paleozoic and Mesozoic rocks in south-central Montana; with descriptions of fauna of Amsden and Heath Formations by L. L. Sloss. Butte, Montana School of Mines, 1946. 100p. (Montana State Bureau of Mines and Geology. Memoir no. 24)

25. Gries, John Paul. Lower Cretaceous stratigraphy of South Dakota and the eastern edge of the Powder River Basin. Wyoming Geological Association, Guidebook 17:163-172. 1962.

26. Hares, C. J. Gastroliths in the Cloverly Formation. Washington Academy of Sciences, Journal 7:429. 1917.

27. Haun, J. D. and J. A. Barlow, Jr. Lower Cretaceous stratigraphy of Wyoming. Wyoming Geological Association, Guidebook 17:15-22. 1962.

28. Henbest, L. G. Pennsylvanian foraminifera in the Amsden Formation and Tensleep Sandstone, Montana and Wyoming. Billings Geological Society, Guidebook 5:50-53. 1954.

29. ________________. Foraminifera and correlation of the Tensleep Sandstone of Pennsylvanian age in Wyoming. Wyoming Geological Association, Guidebook 11:58-63. 1956.

30. Hewett, D. F. and C. T. Lupton. Anticlines in the southern part of the Big Horn Basin, Wyoming. U. S. Geological Survey, Bulletin 656:1-192. 1917.

31. Imlay, R. W. Characteristic marine Jurassic fossils from the western interior of the United States. U. S. Geological Survey, Professional Paper 214-B:13-33. 1948.

32. ________________. Marine Jurassic formations in the Pryor Mountains and northern Big Horn Mountains, Montana. Billings Geological Society, Guidebook 5:54-64. 1954.

33. Imlay, R. W. et al. Marine Jurassic formations of Montana. Washington, D. C., 1948. one sheet. (U. S. Geological Survey Oil and Gas Preliminary Chart no. 32)

34. Knappen, R. S. and G. F. Moulton. Geology and mineral resources of parts of Carbon, Big Horn, Yellowstone, and Stillwater Counties, Montana. U. S. Geological Survey, Bulletin 822A:1-70. 1931.

35. Knechtel, M. M. and S. H. Patterson. Bentonite deposits in marine Cretaceous formations, Hardin district, Montana and Wyoming. U. S. Geological Survey, Bulletin 1023:1-46. 1956.

36. Kummel, Bernhard. Paleoecology of Lower Triassic formations of southeastern Idaho and adjacent areas. In: Treatise on marine ecology and paleoecology, ed. by Joel W. Hedgpeth. Vol. 2. Washington D. C., Geological Society of America, 1957. p. 437-468. (Memoir no. 67)

37. Lammers, E. C. H. The origin and correlation of the Cloverly Conglomerate. Journal of Geology 47:113-132. 1939.

38. Leighton, M. W. and C. Pendexter. Carbonate rock types. In: Classification of carbonate rocks, ed. by W. E. Ham. Tulsa, Oklahoma, American Association of Petroleum Geologists, 1962. p. 33-61. (Memoir no. 1)

39. Love, J. D. et al. Cretaceous and non-marine Jurassic rocks of central Wyoming. Washington, D. C., 1945. one sheet. (U. S. Geological Survey Oil and Gas Preliminary Chart no. 13.)

40. Lupton, C. T. Oil and gas near Basin, Big Horn County, Wyoming. U. S. Geological Survey, Bulletin 621:157-190. 1916.

41. MacKenzie, D. B. and D. M. Poole. Provenance of Dakota Group sandstones of the western interior. Wyoming Geological Association, Guidebook 17:62-71. 1962.

42. Moberly, Ralph, Jr. Morrison, Cloverly and Sykes Mountain Formations, northern Big Horn Basin, Wyoming and Montana. Geological Society of America, Bulletin 71:1137-1167. 1960.

43. ________________. Lower Cretaceous history of the Big Horn Basin, Wyoming. Wyoming Geological Association, Guidebook 17:94-101. 1962.

44. Mook, Charles Craig. The fore and hind limbs of Diplodocus. American Museum of Natural History, Bulletin 37:355-360. 1917.

45. Ostrom, John H., Assistant Curator, Peabody Museum of Natural History, Yale University, New Haven, Connecticut. Personal communication. April 29, 1966.

46. Paull, R. A. Depositional history of the Muddy Sandstone, Big Horn Basin, Wyoming. Wyoming Geological Association, Guidebook 17:102-117. 1962.

47. Peale, Albert Charles. The Paleozoic section in the vicinity of Three Forks, Montana. U. S. Geological Survey, Bulletin 110:1-45. 1893.

48. Peck, R. E. Lower Cretaceous Rocky Mountain nonmarine microfossils. Journal of Paleontology 15:285-304. 1941.

49. Peck, R. E. and W. W. Craig. Lower Cretaceous nonmarine ostracods and charophytes of Wyoming and adjacent areas. Wyoming Geological Association, Guidebook 17:33-43. 1962.

50. Perry, E. S. Montana in the geologic past. Montana Bureau of Mines and Geology, Bulletin 26:1-78. 1962.

51. Pettijohn, F. J. Sedimentary rocks. 2d ed. New York, Harper and Brothers, 1957. 718p.

52. Potter, Paul Edwin. Late Mississippian sandstones of Illinois. Urbana, 1962. 36p. (Illinois State Geological Survey. Circular no. 340)

53. Reeside, J. B. Triassic-Jurassic 'Red Beds' of the Rocky Mountain region: a discussion. Journal of Geology 37:47-63. 1929.

54. Reeside, J. B., Jr. and W. W. Cobban. Studies of the Mowry Shale (Cretaceous) and contemporary formations in the United States and Canada. U. S. Geological Survey, Professional Paper 355:1-126. 1960.

55. Richards, P. W. Geology of the Big Horn Canyon-Hardin area, Montana and Wyoming. U. S. Geological Survey, Bulletin 1026:1-93. 1955.

56. Richards, R. W. and G. R. Mansfield. The Bannock overthrust, a major fault in southeastern Idaho and northwestern Utah. Journal of Geology 20:681-709. 1912.

57. Rubey, W. W. Origin of the siliceous Mowry Shale of the Black Hills region. U. S. Geological Survey, Professional Paper 154:153-170. 1929.

58. Sandberg, C. A. Distribution and thickness of Devonian rocks in Williston Basin and in central Montana and north-central Wyoming. U. S. Geological Survey, Bulletin 1112-D:105-127. 1961.

59. ________________. Widespread Beartooth Butte Formation of Early Devonian age in Montana and Wyoming and its paleogeographic significance. American Association of Petroleum Geologists, Bulletin 45:1301-1309. 1961.

60. Shaw, A. B. The Cambrian and Ordovician of the Pryor Mountains, Montana, and the northern Big Horn Mountains, Wyoming. Billings Geological Society, Guidebook 5:32-37. 1954.

61. Sloss, L. L. Paleozoic sedimentation in Montana area. American Association of Petroleum Geologists, Bulletin 34:423-451. 1950.

62. Thom, W. T., Jr. Tectonic team-research, key to social progress and world-peace. New York Academy of Sciences, Transactions, ser. 2, 14:146-151. 1952.

63. Thom, W. T., Jr. et al. Geology of Big Horn County and the Crow Indian Reservation, Montana. U. S. Geological Survey, Bulletin 856:1-200. 1935.

64. Thomas, H. D. Phosporia and Dinwoody tongues in lower Chugwater of central and southeastern Wyoming. American Association of Petroleum Geologists, Bulletin 18:1655-1697. 1934.

65. Verville, G. J. Wolfcampian fusulinids from the Tensleep Sandstone in the Big Horn Mountains, Wyoming. Journal of Paleontology 31:349-352. 1957.

66. Washburne, C. W. Gas fields of the Big Horn Basin, Wyoming. U. S. Geological Survey, Bulletin 340:348-363. 1908.

67. Weller, J. M. et al. Correlations of the Mississippian formations of North America. Geological Society of America, Bulletin 59:91-196. 1948.

68. Williams, H., F. J. Turner and C. M. Gilbert. Petrography. San Francisco, Freeman, 1958. 406p.

69. Williams, J. S. Mississippian-Pennsylvanian boundary problems in the Rocky Mountain region. Journal of Geology 56:327-351. 1948.

70. ________________. Pennsylvanian System in central and northern Rocky Mountains. In: Pennsylvanian System in the United States: a symposium, ed. by C. C. Branson. Tulsa, American Association of Petroleum Geologists, 1962. p. 159-187.

71. Wilson, P. C. Pennsylvanian stratigraphy of Powder River Basin and adjoining areas. In: Pennsylvanian System in the United States: a symposium, ed. by C. C. Branson. Tulsa, American Association of Petroleum Geologists, 1962. p. 117-158.

72. Wulf, George R. Lower Cretaceous Albian rocks in Northern Great Plains. American Association of Petroleum Geologists, Bulletin 46:1371-1415. 1962.