THE STRUCTURAL AND STRATIGRAPHIC FRAMEWORK OF THE WARM SPRINGS RANCH AREA, HOT SPRINGS COUNTY, WYOMING

By

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THE STRUCTURAL AND STRATIGRAPHIC FRAMEWORK OF THE WARM SPRINGS RANCH AREA, HOT SPRINGS COUNTY, WYOMING

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CHAPTER I

INTRODUCTION

Purpose

The goal of this endeavor was to provide a detailed account of the stratigraphy and areal geology of the Warm Springs Ranch and of the immediately surrounding area. Within the study area are many locations of interest for the study of vertebrate and invertebrate paleontology. I hope that the information presented here will aid in the location of fossil-collection and study sites, as well as contribute general geologic knowledge of interest to the Wyoming Dinosaur Center. To accomplish this goal a geologic map (Plate I) was compiled covering the study area. The map includes units from the Phosphoria through the Frontier Formation. In conjunction with mapping, portions of the stratigraphic section were measured at various locations within the study area. Six measured sections were prepared that cover rock units from the top of the Phosphoria Formation through the top of the Mowry Formation (Plates II through VII). The resulting map and stratigraphic columns are included as plates in the pocket of this thesis .

Location of Study Area

The study area is located along the southern edge of the Big Horn Basin on the north flank of the Bridger Mountains. It is present in the northeast part of

Hot Springs County, Wyoming, east of Thermopolis, Wyoming (Figure 1). The area is between longitudes 107° 58'30" and 108° 14' and between latitudes 43° 42' 25" and 43° 34' 30". The study area incorporates parts of townships T43N, R93W; T43N, R94W; T42N, R93W; T42N, R94W; T42N, R95W; T43N, R95W.

Boundaries of the study area are defined on the south by Buffalo Creek Road, on the northwest by the Mowry hogback, and on the west by the Bighorn River. The remainder of the area boundaries are placed at various section lines, as is shown in Figure 2.

Methods of Investigation

Preparation

Black-and-White 9 inch x 9 inch aerial photographs were obtained covering the thesis area. The photography was compiled from three flights, in 1994, 1995, and 1996. Scales of the photographs are similar enough to cause no problems. All geologic data collected were recorded on mylar sheets superimposed on the photographs. Thus, no data were put directly on the photos themselves.

For base maps, U.S. Geological Survey 7.5-minute series topographic maps and 7.5-minute orthographic quadrangles were obtained from the USGS. Quadrangle maps used were Thermopolis, Red Hole, Coyote Hill, Wedding of the Waters, Devil Slide, and Blue Hill. The Thermopolis Orthographic

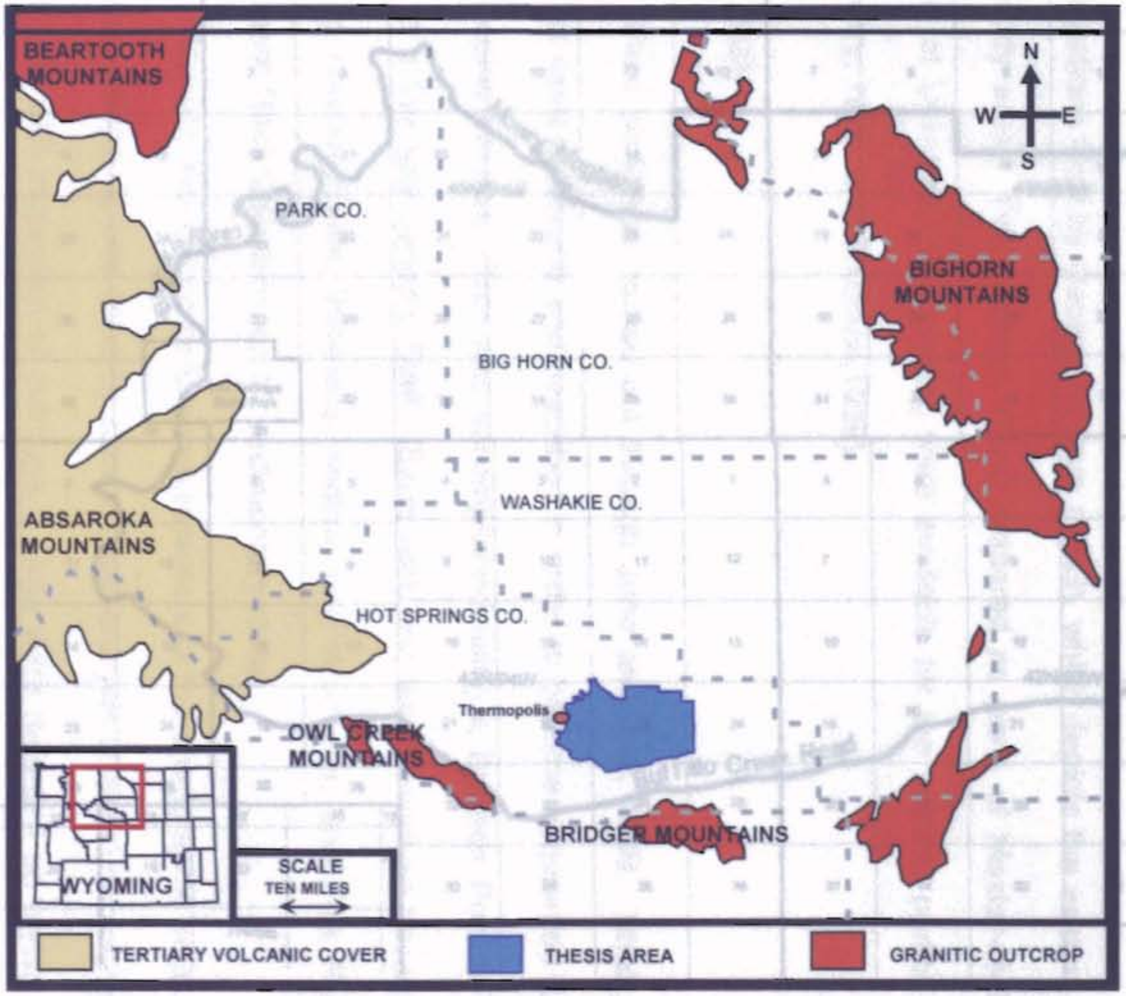

Figure 1. Location of the study area. Modified from Schmude (2000)

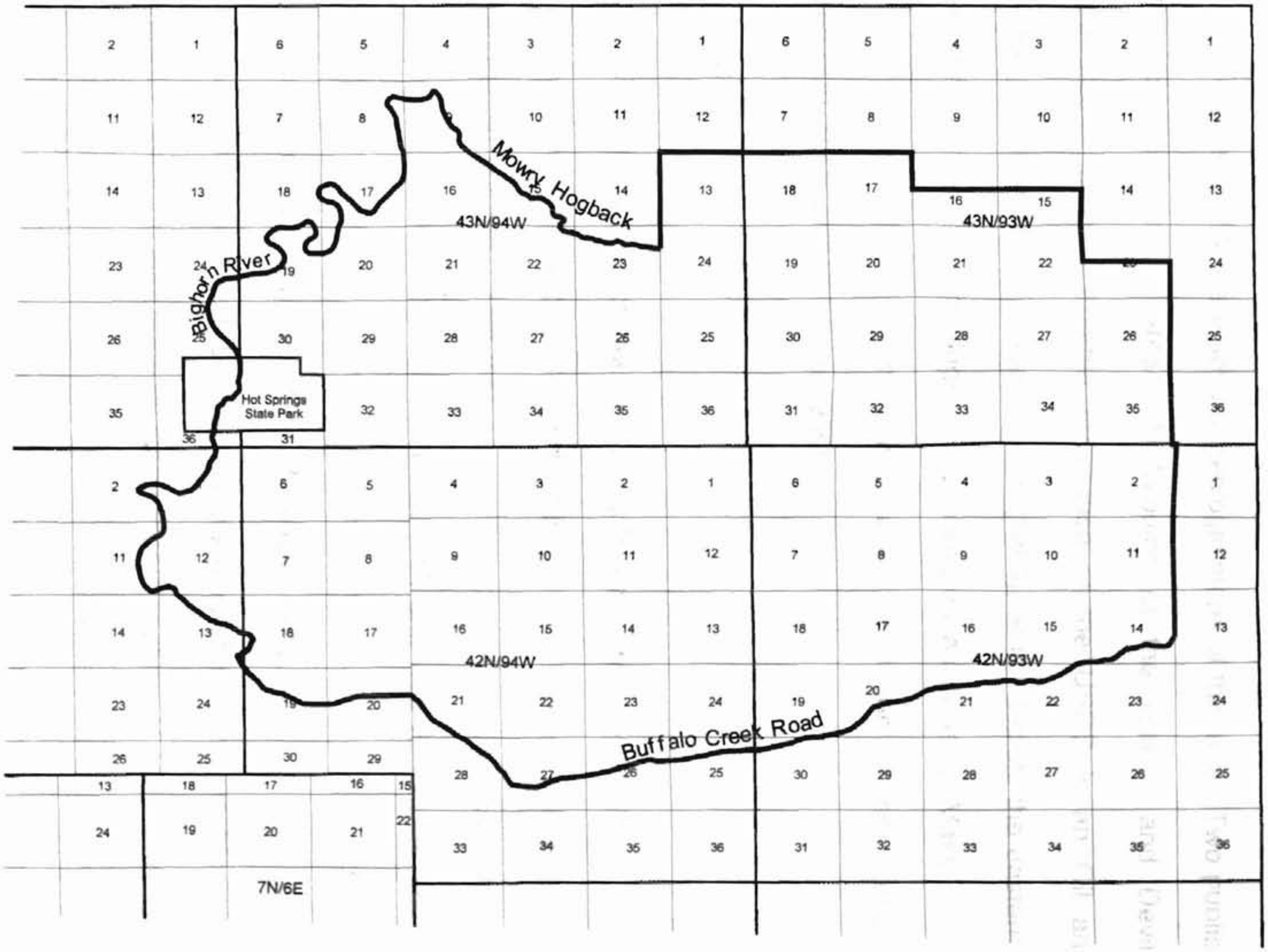

Figure 2. Study area, defined by townships and sections. The boundary is shown by the heavy black line.

Quadrangle was not available from the USGS at the time the field work was conducted.

Also available were several geologic maps of the area. Two published by the USGS cover the areas of Wedding of the Waters and Devil Slide Topographic maps. Another publication of the USGS is an Oil and Gas Investigations Map by George H. Horn (1963), which depicts the eastern half of the study area. Two geologic maps prepared as parts of Master-of-Science theses at University of Wyoming were available for the eastern portion of the area (Ary, 1958, and Shlemon,1959).

Field Work

Field work was carried out through June and July, 1999. Stratigraphic sections were measured and described in order to become acquainted with the stratigraphic column. This was accomplished using a Brunton Pocket Transit fixed to a five foot Jacob's Staff. Each rock unit was described based on its bedding characteristics, thickness, sedimentary structures, and Folk Five-Fold Siliciclastic Rock Classification for sedimentary rocks.

Mapping was begun before measurement of the stratigraphic section was complete. Mapping was done by stereoscopic analysis of aerial photographs, in conjunction with inspection of outcrops. Data were recorded on mylar sheets that covered the individual photographs. The thesis area is transected by numerous unimproved dirt roads and by many oilfield-access roads. With the time frame allowed, much mapping was done from the cab of a pick-up truck.

Questionable areas or inaccessible areas were inspected on foot. Data that were collected on the mylar sheets were transferred from aerial photographs to orthographic quadrangle maps, then traced directly onto the topographic maps. This procedure was carried out for each quadrangle except the Thermopolis Quadrangle, where these data were transferred directly from the 9 inch x 9 inch photograph to the topographic map.

CHAPTER II

STRATIGRAPHY

Introduction

Rocks of the study area are restricted to the interval between the upper part of the Permian Phosphoria Formation and the base of the Cretaceous Frontier Formation. The discussion of stratigraphy will be limited to strata within this range as they are expressed within the thesis area. The stratigraphic nomenclature applied in this thesis is outlined in Figure 3.

Triassic System

Dinwoody Formation

The Dinwoody interval was described first by Darton (1906a). He included the Dinwoody in the Embar Formation, which was composed of all rocks between the Pennsylvanian Tensleep Sandstone and Triassic Chugwater unit. The name Dinwoody was first used by Condit (1916) to describe the non-red bed, Triassic portion of the Embar. Balckwelder (1918) formally named the Dinwoody Formation as it is constituted now and this definition has been accepted by subsequent workers (Paull and Paull, 1990).

Within the study area the Dinwoody Formation crops out primarily in two specific areas: along the axis of the Red Spring Anticline in Red Hole, and along the axis of the Thermopolis Anticline, near the western boundary of the study

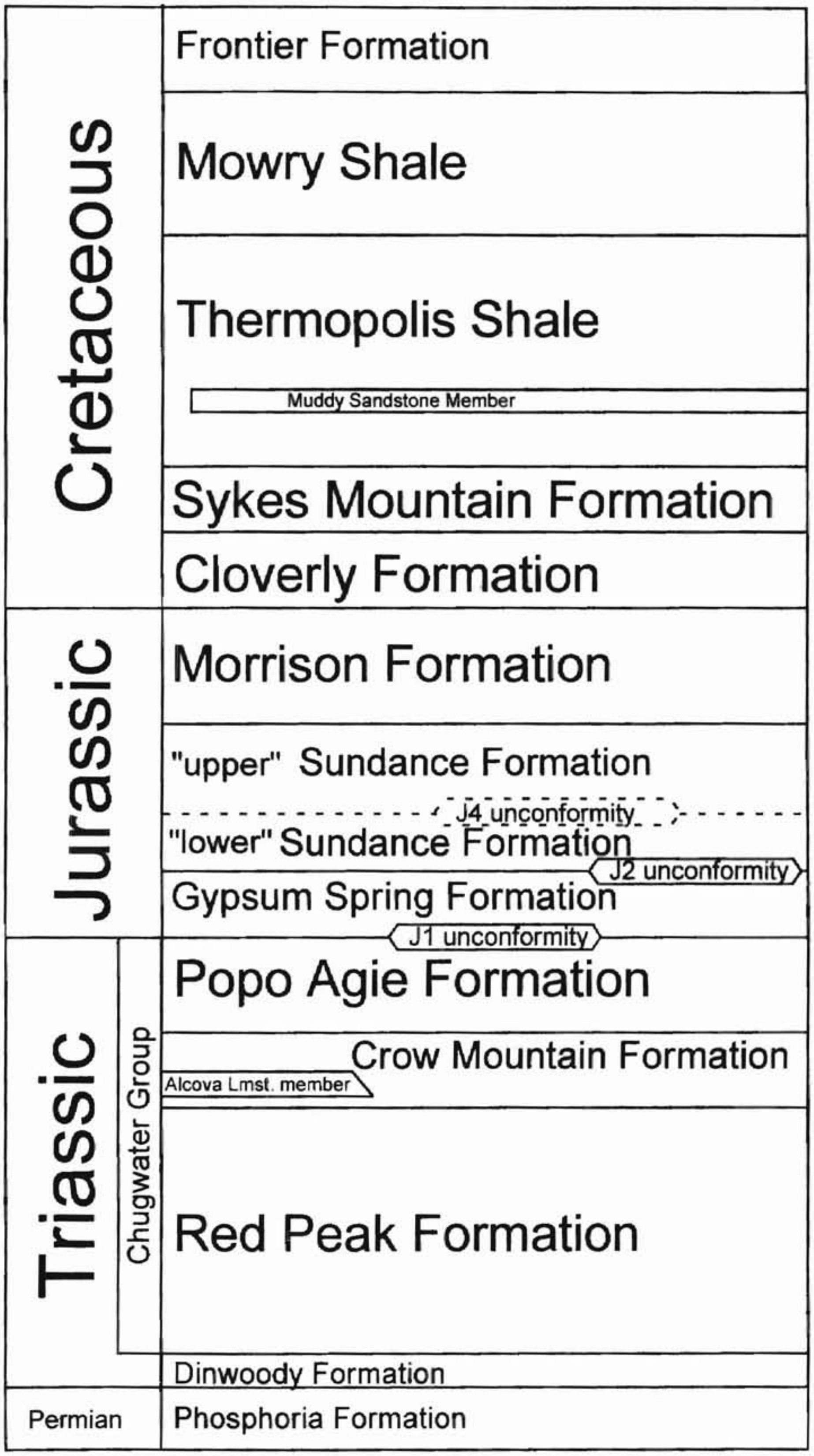

Figure 3. Stratigraphic nomenclature for the Warm Springs Ranch Area

area. The Dinwoody weathers to form rounded hills showing slightly greater topographic expression than that seen with the lower part of the overlying Red Peak Formation. Vegetation supported by soils on the Dinwoody consists mostly of grasses.

The Dinwoody has a sharp contact with the underlying Phosphoria Formation (Plate II, Measured Section 1). The writer found no visible evidence of erosion at the contact. Conodonts collected by Paull and Paull (1986) from the basal part of the Dinwoody led those workers to conclude that deposition of the Dinwoody started in the earliest Triassic. On the grounds of this interpretation, missing time at the Permian-Triassic disconformity was assigned to the Permian (Paull and Paull, 1990).

Deposition of the Dinwoody in the study area began with a thin bed (3 feet) of nonfibrous gypsum containing some light gray mudstone. The proportion of mudstone increases upward, and the upper part of the bed is gypsiferous mudstone. The gypsum in these units occurs as fibrous interbeds and stringers. One thick (27.5 feet) gypsum-dominated unit occurs near the middle of the formation (Figure 4). It is argillaceous and contains fibrous-to-powdery, laminated gypsum. Above this is 34 feet of mud shale containing 1/8-in.-thick gypsum crusts and pyrite crystals that weather to limonite. The upper contact of the Dinwoody is represented by a sharp color change, where the mud shale abruptly changes to brick red. Many fibrous gypsum crusts are present in the Red Peak directly above the contact and these crusts continue into the Red

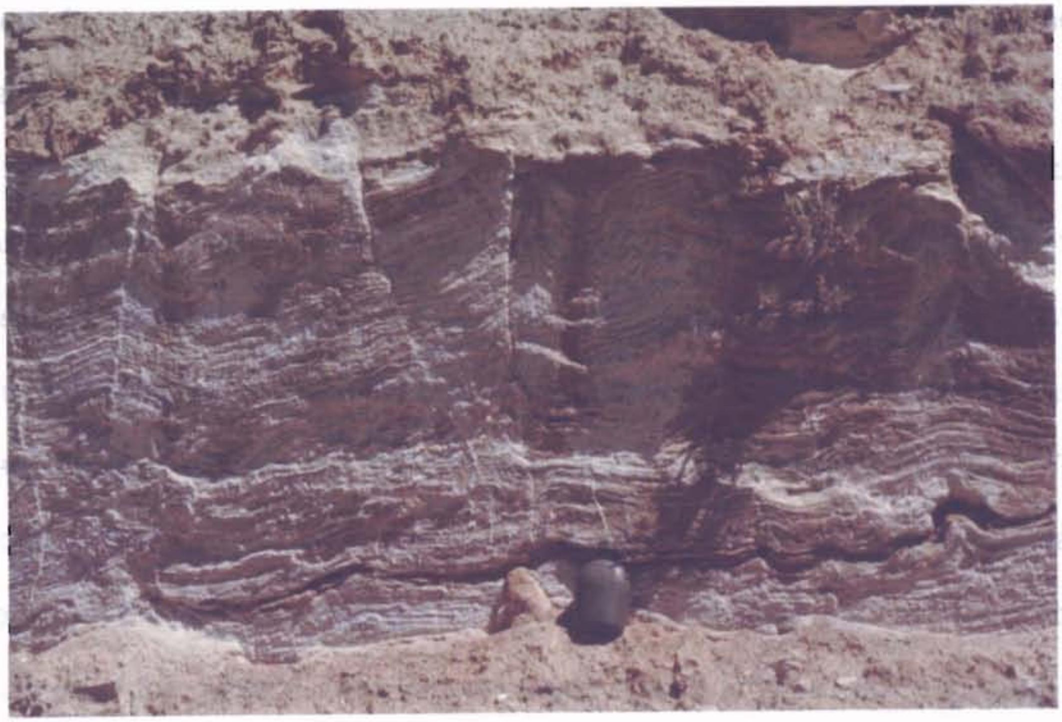

Figure 4. Laminated Gypsum of the Triassic Dinwoody Formaiton. Canteen at base of outcrop for scale. Canteen is approximatley 6 inches tall. This photograph was taken of outcrop near the base of Measured Section 1, at Red Hole.

Peak. The sharp contact between the Dinwoody and Red Peak is interpreted to be conformable (Paull and Paull, 1990).

The formation of evaporites in the shallow basin that existed here in the Triassic gives insight to the prevalent climate. Gypsiferous evaporites are generally accepted as having been deposited in areas with arid climates, where the rate of evaporation exceeds the rate of freshwater influx (Boggs, 1995). The Dinwoody in the study area is relatively close to the depositional limit found by Paull and Paull (1990), which parallels the Bighorn Mountains. Considering the position of the present study area relative to the depositional limit, as well as the abundance of mud shale in the formation, Dinwoody deposition within the study area probably was in a shallow marine environment, possibly on mud flats. The middle laminated unit shows evidence of being deposited in deeper water than the rest of the formation due to the decrease in silt content and the laminated structure of the gypsum. The laminated unit is likely to have been deposited in a deeper basinal setting than the rest of the formation, below wave influence and below the photic zone (Kendall, 1992). Where recorded for Measured Section 1 the Dinwoody formation is 87 feet thick.

Chugwater Group

The Chugwater was defined first as a formation by Darton (1904). The type locality is along Chugwater Creek in the Laramie Mountains. The original definition included all red beds between the Pennsylvanian Tensleep Formation and the Jurassic Sundance Formation. The first division of the Chugwater

Formation was proposed when Williston (1904) used the name "Popo Agie beds" to describe an interval of outcrop that yielded vertebrate fossils close to the Popo Agie River near Lander, Wyoming. Williston did not define the unit beyond giving the approximate position of the interval within the red beds and the thickness of the unit. The light-colored limestones and claystones, which were near the base of the early-defined Chugwater, were redefined by Darton (1906) as the Embar Formation. These rocks have since been renamed as the Permian Phosphoria and Triassic Dinwoody Formations. A thin limestone unit near the top of the Chugwater interval recorded by Knight (1897) and Darton (1906b), was named by Lee (1927) as the Alcova Limestone Member.

Current names of the Chugwater subdivisions were first proposed by Love (1939), when he subdivided the formation into the Red Peak, Crow Mountain, Popo Agie and Gypsum Spring Members. All of these names were proposed for the first time, except for the Popo Agie, which was formally defined for the first time. Branson and Branson (1941) proposed several revisions to the Chugwater nomenclature. They attempted to raise the Chugwater to group status and redefine the members as formations. Due to apparent discrepancies in their work, the terminology proposed by Branson and Branson (1941) was never accepted. The last accepted Chugwater revision was made by High and Picard (1967). In their publication, the Chugwater was raised to group status. The group was described as being composed of three formations: Red Peak, Crow Mountain, and the Popo Agie (Figure 3). They included the Alcova Limestone as a member of the Crow Mountain Formation. Nomenclature of the Chugwater used in this work is that proposed by High and Picard (1967). The total thickness of the Chugwater group was recorded in Measured Section 1 as 883 feet.

Red Peak Formation. High and Picard (1967) presented an informal, lithologic division of the Red Peak. Based on descriptions of these informal units by Picard (1978), each one has been identified in the Red Peak. These units are described in Section 1 (Plate II). The silty claystone facies comprises the bottom 205 feet of the formation. This interval is mainly composed of mud shale, but is siltstone dominated in the upper one third of the unit (Figure 5). This unit was broadly interpreted by Picard (1993) to have been deposited in a transitional paralic setting. Definite interpretation of this unit is difficult because of the sparsity of diagnostic sedimentary structures. The author of this thesis does concur with the interpretation of a paralic setting, a conclusion based on sediment type, vertically adjacent depositional settings, and the few visible sedimentary structures observed.

Overlying the silty claystone facies is the 159-foot-thick lower platy facies. This interval of the Red Peak consists of mudstone, coarse siltstone, and silty, very fine-grained sandstone. The sandstone and siltstones are trough cross-bedded and show evidence of some ripple lamination as well as distinct ripples on bedding planes. In the upper part of the lower platy facies the siltstones are plane-bedded. These strata probably are the record of some degree of sea level fluctuation. The coarse grained cross-bedded units most likely represent near-shore sedimentation in 5 to 10 feet of water (Davis, 1992).

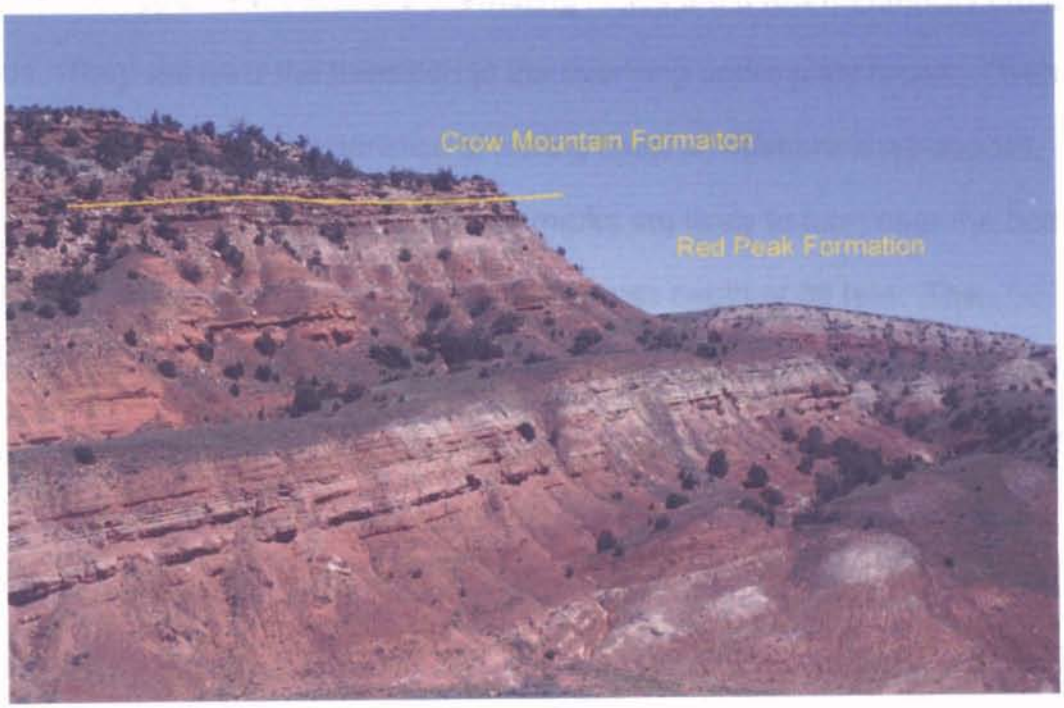

Figure 5. Typical appearance of the Red Peak in area of Measured Section 1.

The 225 feet of rock above the lower platy facies is Picard's alternating facies. This interval changes from a coarse siltstone with ripple marks at the base of the unit to silty very-fine sandstone near the top. Approximately 95 feet below the upper formation contact is a micrite limestone interval interbedded with shale. This set of strata forms a clearly visible light-colored "band" on the slope. Within the upper few feet of the alternating facies are a few hummocky cross-beds. They are near the transition to the overlying upper platy facies. Overall this interval shows characteristics of having been an offshore shelf deposit, possibly deepening upward. The ripple marks are likely to form near the bottom of the fair-weather wave base at an approximate depth of 30 feet. The hummocky cross bedding in the upper few feet would form below the fair-weather wave base under storm influence (Boggs, 1995). An oil seep was found in N1/2, NE1/4, NE1/4, of sec. 29, T43N, R 93W, coming from the "alternating facies.

The upper platy facies is the last of the informal units in the Red Peak proposed by Picard. It occupies the uppermost 24 feet of the formation at the location of Measured Section 1 (Plate II). The rocks of this interval are silty very fine sandstones with mudstone and siltstone interbeds. The sand and siltstones contain hummocky cross-bedding and some convolute bedding. A few sets of four-toed vertebrate tracks were found on a slab, displaced from a bed within this interval. These tracks are probably similar to the tracks described by Boyd and Loope (1984). Those authors concluded that the tracks were produced by an amphibious tetrapod. The hummocky cross-bedding, convolute bedding, and few ripple marks suggest that at least parts of this interval were deposited at the bottom of the fair-weather wave base. Vertebrate trace fossils may suggest that this was occasionally within the intertidal zone. The total thickness of the Red Peak Formaion is 605 feet.

The lower contact of the Red Peak appears to be conformable. The contact was chosen based on the sharp color change and the decreased amount of gypsum in the Red Peak compared to the Dinwoody. The upper contact with the Crow Mountain, also appears to be conformable. Similar sediment type and sedimentary structures are present in the lower Crow Mountain. Picard (1978) made mention of the high degree of difficulty of placing formation contacts within the Chugwater Group. The upper Red Peak contact was designated as being between the interbedded mudstone and siltstone of the Red Peak and the massive fine sandstone of the Crow Mountain.

The Red Peak Formation crops out continuously along the southern margin of the study area above Buffalo Creek Road, and is also present in the Thermopolis Anticline. However, the best exposure of the formation is on the north flank of the Red Spring Anticline. The lower part of the Red Peak typically forms a gentle slope that is covered with grass. At some localities this part of the formation is expressed topographically as low hills and small buttes. The upper part of the formation usually displays a steeper gradient leading up to the overlying Crow Mountain, and is typically sparsely vegetated.

Crow Mountain Formation. The lower unit of the Crow Mountain is silty very fine-grained sandstone, with abundant hummocky cross bedding. This would suggest that the unit was deposited in a marine setting below the fair-weather wave base. The contact of this lower Crow Mountain unit with the Alcova Member is generally considered to be irregular and slightly disconformable (Picard, 1967). The lower contact as it is seen in the study area is abrupt, and undulating, possibly erosional (Figures 6 and 7). The upper Alcova contact is also erosional, as is demonstrated clearly by granules and pebbles originating from the Alcova deposited in the base of the overlying Crow Mountain unit (Figure 8), and by the laterally discontinuous nature of the Alcova. The algal laminations in the micritic carbonate unit led the author to infer a shallow marine depositional environment for the Alcova Limestone Member. The Alcova is reputed to be the best surface and subsurface marker bed in Wyoming, because it occurs over an enormous area. How much of the Alcova was lost to the erosional unconformity at the upper contact is not clear. Due to this erosion the Alcova, likely does not extend to its original depositional limits. The remainder of the Crow Mountain is very fine-grained sandstone containing indistinct trough cross beds. The Crow Mountain above the Alcova was likely deposited in a near-shore, to upper shoreface setting.

Exposure of the Crow Mountain is extensive along the southern margin of the study area, where it caps high hills and forms major bluffs. Along the north flank of the Thermopolis Anticline the Crow Mountain forms much less extreme bluffs and cliffs, but displays excellent outcrop nevertheless. The Crow Mountain Formation crops out well in the north flank of the Red Spring Anticline, where it was examined for Measured Section 1 (Plate II). The formation weathers to form nearly vertical bluffs and has an abundance of cedar trees.

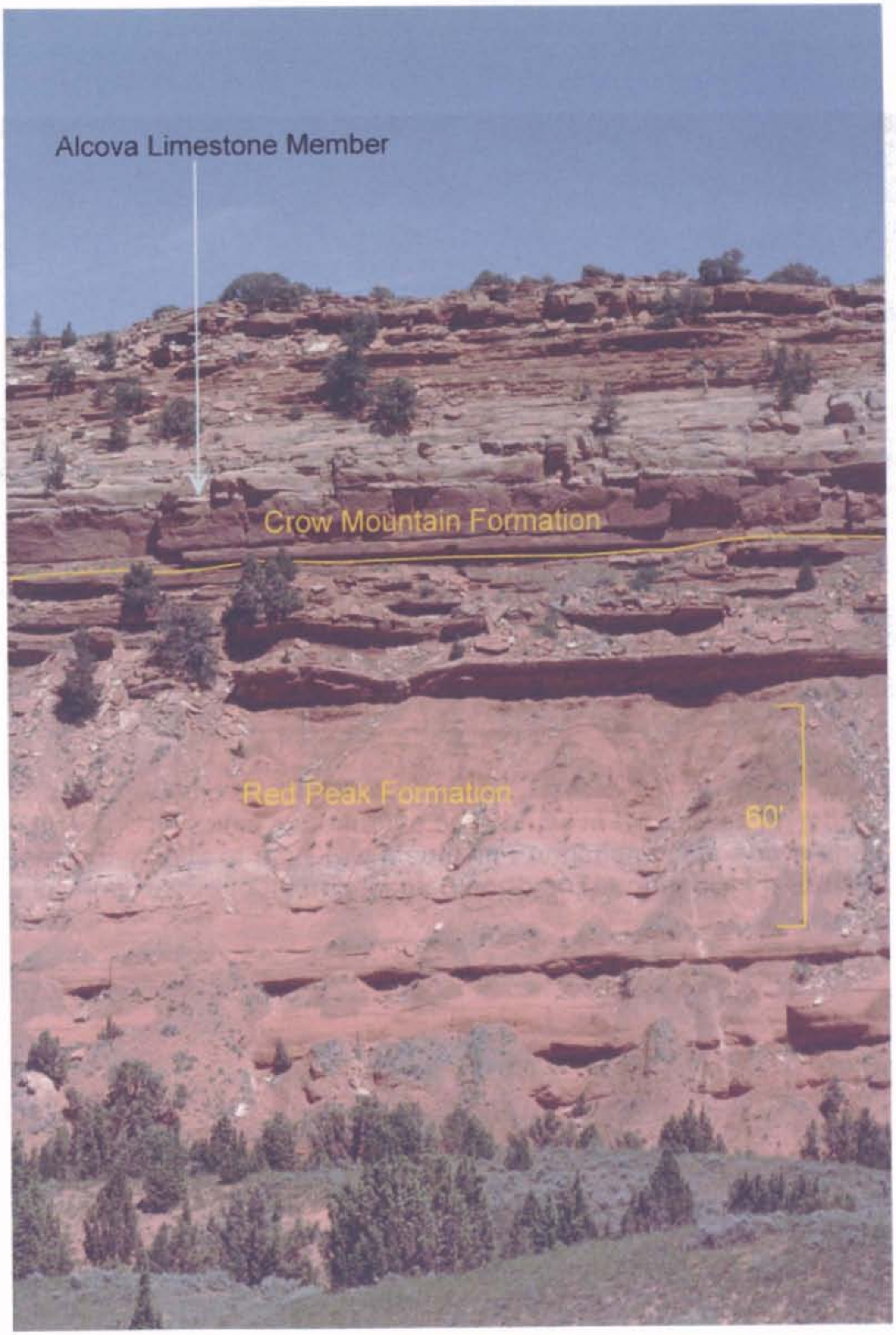

Figure 6. Uppermost Red Peak Formation and contact with the Crow Mountain Formation. The Alcova Limestone Member is the thin light colored band on the cliff pointed out by the arrow. Outcrop located on the north flank of Red Hole.

Figure 7. Typical appearance of the Alcova Limestone Member. Sandstone units of the Crow Mountain Formation occur above and below the Alcova. Outcrop located north of Thermopolis on E. River Road.

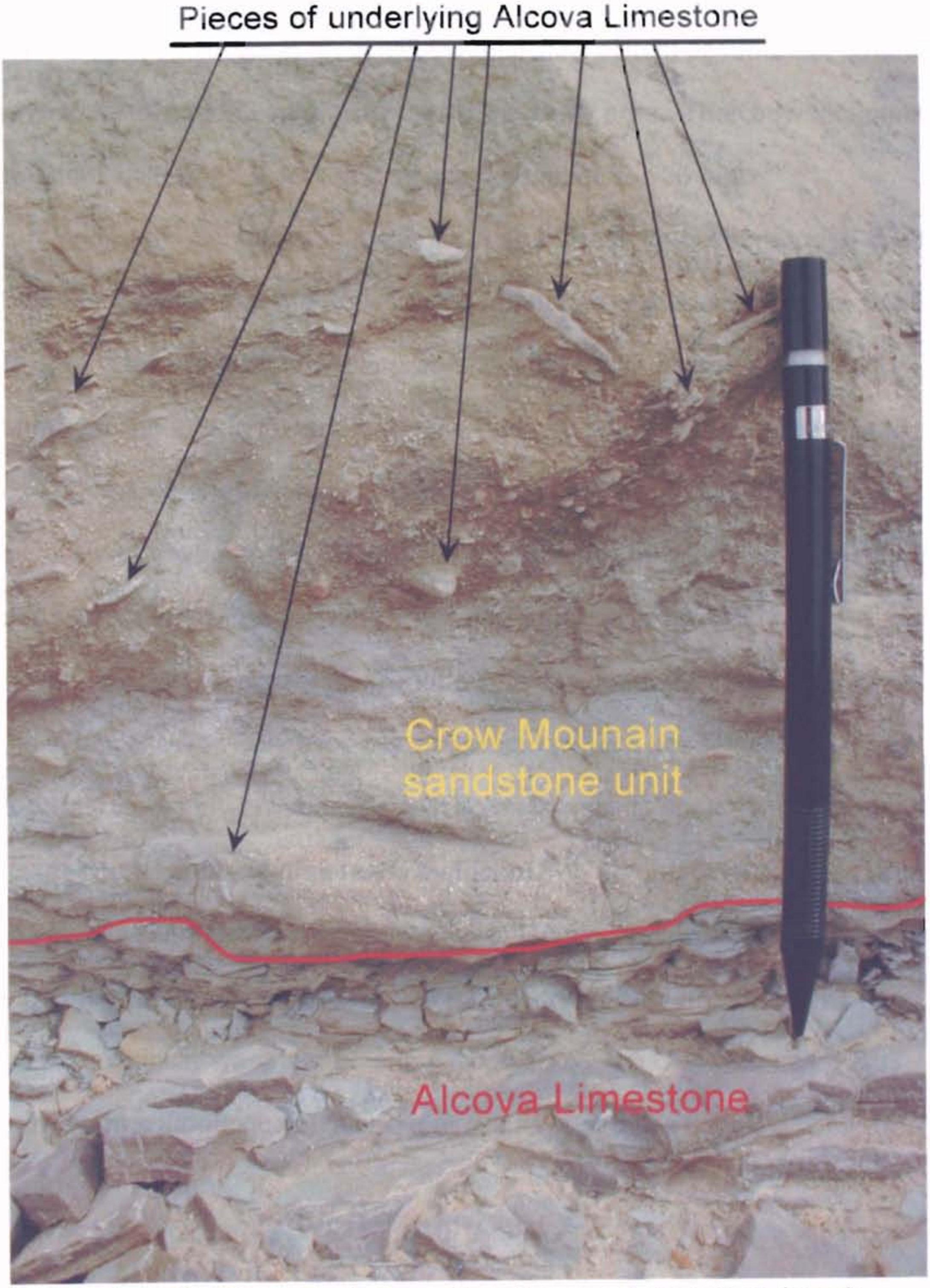

Figure 8. Photograph of Crow Mountain sandstone unit directly overlying the Alcova Limestone. Clasts of Alcova are included in the overlying sandstone unit. Pen is approx. 5 inches long.

The Alcova Limestone Member is discontinuous within the thesis area. It is seen thinning toward the west along Buffalo Creek Road. The erosional unconformity at the top of the member is responsible for its inconsistent occurrence. The Alcova thins toward the southwest part of the study area. The Crow Mountain Formation, including the Alcova Limestone Member, is 126 feet.

Popo Agie Formation. The Popo Agie is made up of interbedded sandy siltstone and mudstone. Siltstones in the upper half of the formation are heavily burrowed. One major clue to interpreting the depositional environment is the presence of the zeolite mineral analcime reported by High and Picard (1965). Those authors interpreted the analcime to have originated from volcanic deposits in a lacustrine environment. Some of the siltstones and sandy siltstones in the upper part of the Popo Agie within the thesis area display fluvial channel geometry. Based on observations made by the writer, the Popo Agie Formation of the Warm Springs Ranch area is interpreted to have been deposited in a dominantly lacustrine environment with some fluvial influence. This interpretation is roughly consistent with that made by Picard (1978), and other workers who made similar interpretations based on the presence analcime. The thickness of the formation amounts to 152 feet at the location of Measured Section 1. The Popo Agie typically weathers to form a slope above the Crow Mountain Bluff (Figure 9). It supports junipers and grasses as vegetative cover.

Jurassic System

Gypsum Spring Formation

The Gypsum Spring was defined by Love (1939) as a member of the Chugwater Formation. It has since been classified as Middle Jurassic and raised to formation status by Love et al. (1945).

In the study area the Gypsum Spring is made up of an upper limestone member and a lower gypsum and red claystone member (Figure 9). The formation is bounded by the J_1 unconformity at the base and the J_2 unconformity at the top (Schmude, 2000). The gypsum and red claystone member can be divided into an interval of mostly massive, white powdery gypsum with a few mudstone interbeds in the lower part and an interval of medium brick red mud shale with gypsum nodules and veinlets that decrease in frequency upward. At a few locations in the area the gypsum interval is brecciated. Schmude (2000) proposed that this is due to recent groundwater dissolution and collapse. To support this conclusion he cites the lack of a brecciated facies on subsurface electric logs. The gypsum interval represents deposition in a sabkha of marine evaporite facies. Conditions were altered for the upper part of this interval to allow for dominantly clastic deposition.

The upper limestone member is composed of three separate limestone units with interbedded calcareous shales (Measured Section 2, Plate III). These units have been termed by Schmude (2000) as LS1, LS2, and LS3 from bottom to top, respectively. LS1 is micritic limestone with wavy bedding and abundant

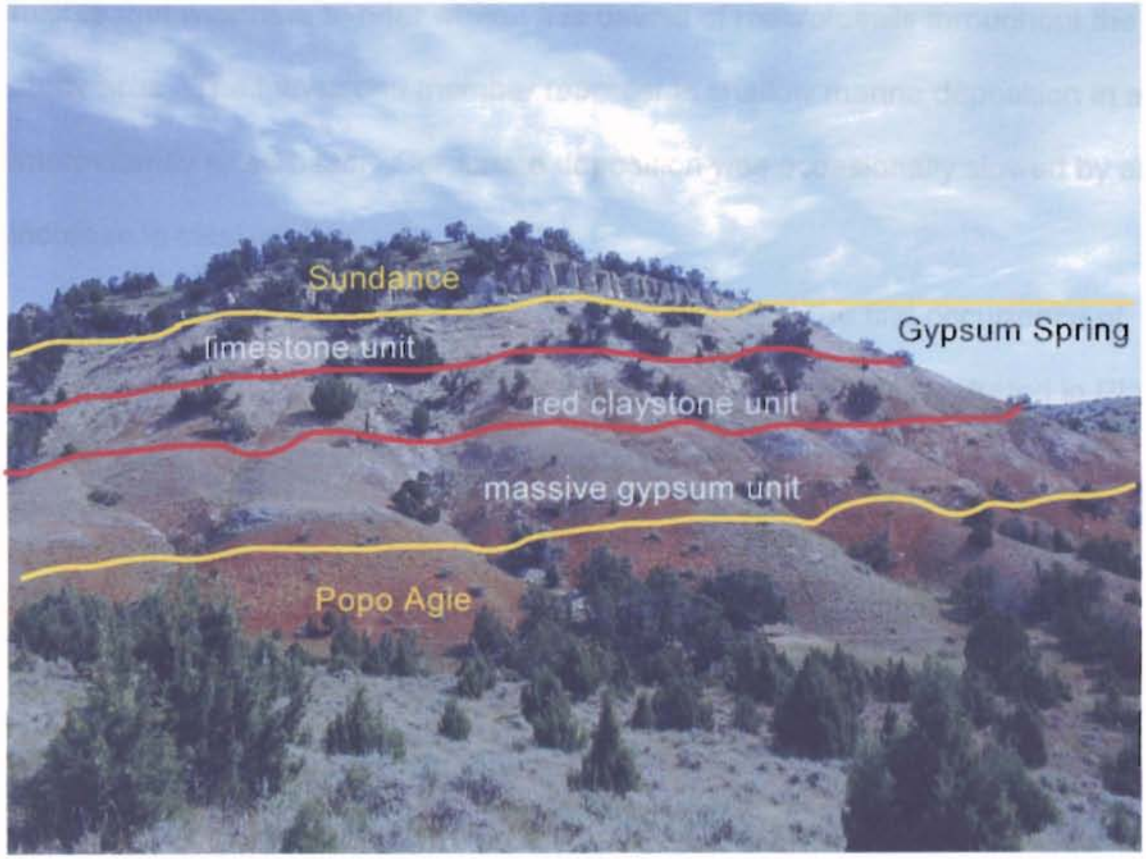

Figure 9. Jurassic Gypsum Spring outcrop. Formation contacts are representd by the yellow lines. Informal member boundaries are represented by the red lines. Outcrop located on the hill north of W. Warm Springs Oil Field.

algal lamination. In the southwest part of the study area a 3-inch thick coquina of intact gastropod shells was found near the top of the unit. LS2 is micrite containing bivalve impressions on some bedding planes. LS3 is a very light gray micrite that weathers to near white. It is devoid of macrofossils throughout the study area. The Limestone member represents shallow marine deposition in an intermittently silled basin. Carbonate deposition was occasionally slowed by an increase in clastic influx.

The lower contact of the formation was placed at the first occurrence of massive bedded gypsum. This surface is the J_1 unconformity, illustrated in Plate III (Measured Section 2). The upper contact is placed at an erosion surface along which chert pebbles, removed from the limestone member, are found (Figure 10). This second surface is designated the J_2 unconformity surface (Schmude, 2000). Above the second disconformity is the Middle Jurassic Sundance Formation. The Gypsum Spring where measured for Measured Section 2 is 144 feet thick.

Gypsum Spring outcrop is usually found on the slopes of hills and hogbacks capped by Cloverly Formation conglomerates. The best exposures are present in the southwest part of the study area and on the north flank of the Red Spring Anticline. Quality of outcrop is usually aided by the lack of vegetative cover. Vegetation, where present, usually consists of sparse grasses.

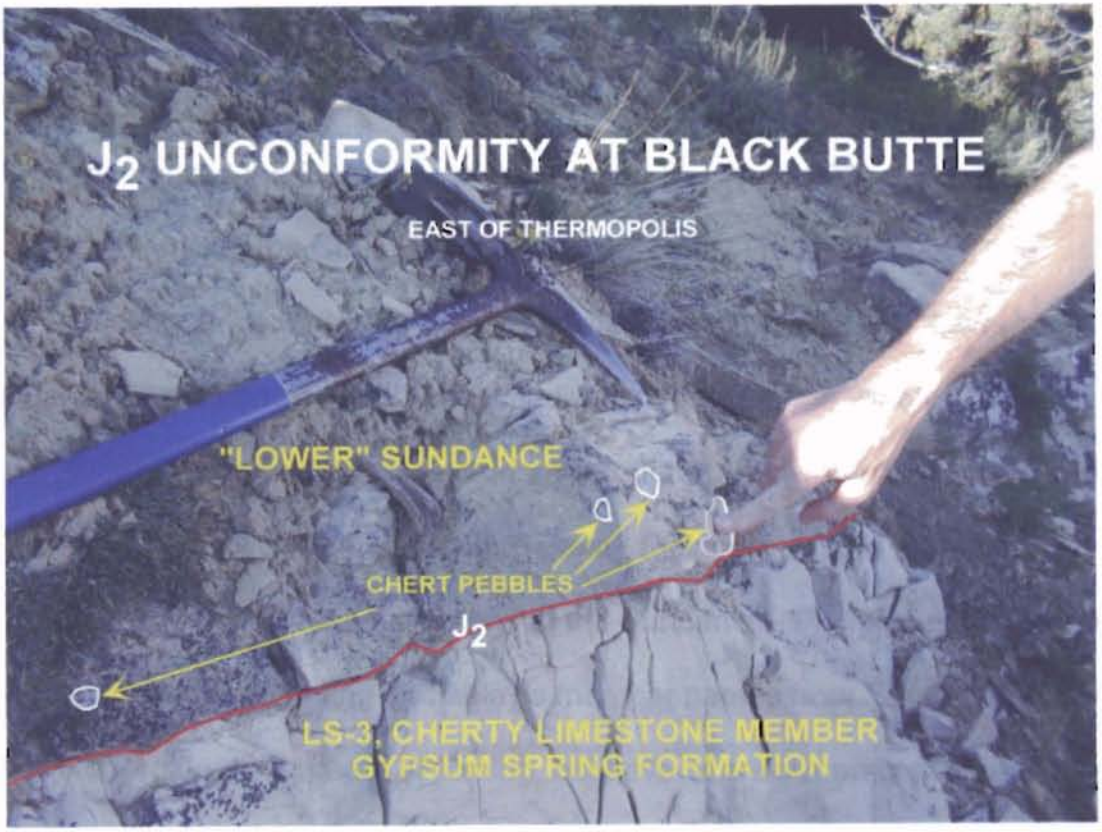

Figure 10. Erosional contact between Jurassic Sundance and Jurassic Gypsum Spring formations. Black chert pebbles, typical of the contact, are highlighted in the photo.

Sundance Formation

Darton (1899) first applied the name Sundance to a sequence of fossiliferous marine shales, sandstones, and red beds overlying the Spearfish Formation and underlying the Morrison Formation near Sundance Wyoming. Darton recognized the Sundance in the Bighorn Basin in 1906 as a marine sequence overlying the Chugwater Formation. Neely (1937) identified two informal subdivisions of the Sundance that he termed "upper" and "lower" Sundance Formation. This informal subdivision has become widely used.

A formal type section was not identified until 1947, when Imlay proposed a section northeast of Spearfish, South Dakota. Pipiringos (1968) and Imlay (1947) have made further subdivisions of the Sundance. Pipiringos' subdivisions from south-central Wyoming and Imlay's member names from South Dakota are difficult to transfer to northern Wyoming, but several are currently accepted. Imlay's (1980) Sundance subdivisions in the Bighorn Basin include the Oolitic Limestone, Stockade Beaver Shale, and Hulett Sandstone Members of the "lower" Sundance and the Red Water Shale Member of the "upper" Sundance.

In the southeast part of the basin, the member names for the "lower" Sundance are difficult to apply. This difficulty results form lateral facies changes and formation thinning caused by the presence of the newly proposed Black Mountain High (Schmude, 2000)(Figure 11). Subdivision of the Sundance for the purposes of this report will not extend beyond the "upper" and "lower" Sundance designations.

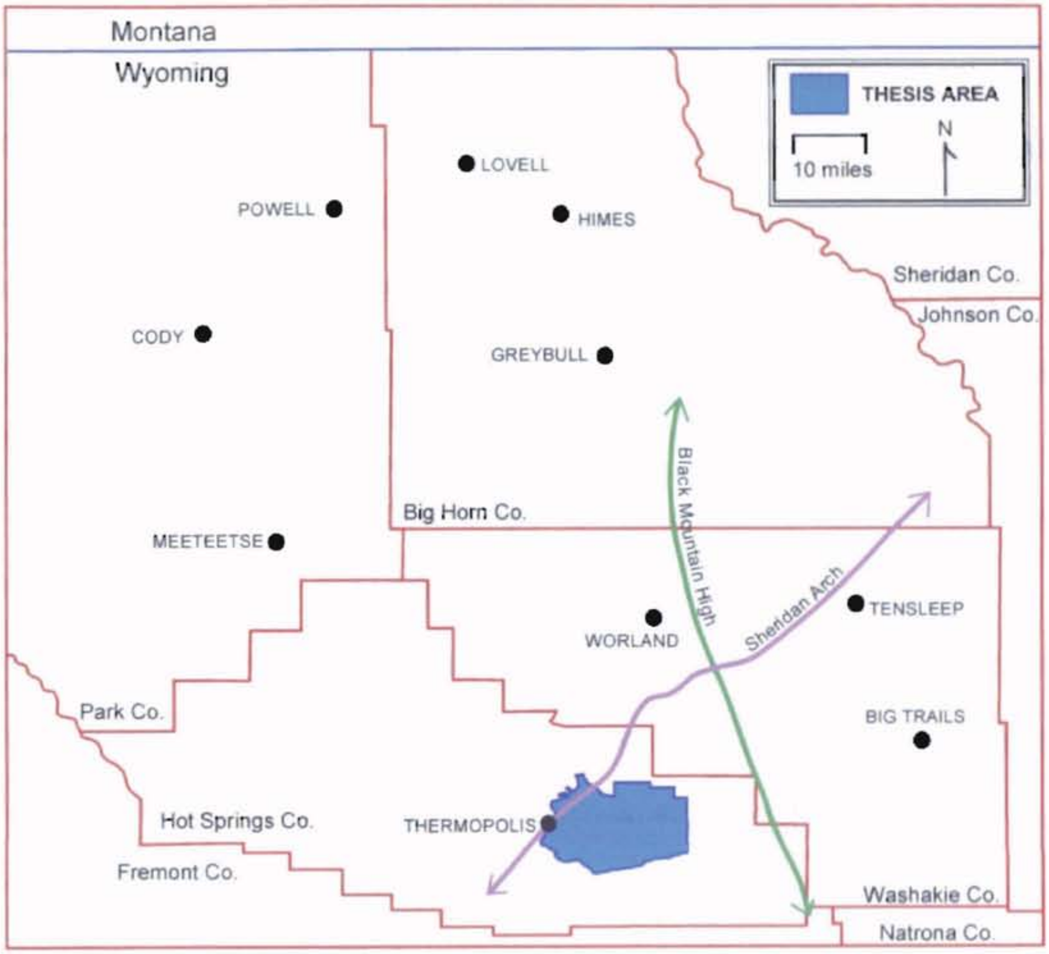

Figure 11. The location of the Black Mountain High and the Sheridan Arch. Modified from Schmude (2000)

"Lower" Sundance deposition began as the area that was transgressed from north to south by the second Jurassic sea. The presence of the Black Mountain High had significant influence on the depositional environments in the basin during the Middle Jurassic. Sundance sediment was initially deposited on the J_2 unconformity surface, which was generated after the withdrawal of the Gypsum Spring sea. The J_2 had its most pronounced effects on the crest of the Black Mt. High, where the upper limestone member is completely removed in some areas.

As the "lower" Sundance sea began to transgress the flanks of the high, an interesting interplay of depositional environments developed which is expressed in the thesis area. The facies accumulated include a laminated, platy limestone facies, a cross-bedded oolitic limestone faces, a chert conglomeratic faces, a interbedded sandstone and shale facies, and a large-scale trough cross-bedded, quartz-arenite sandstone facies. In some cases these facies can be seen interfingering. Figure 12 shows that the sandstone facies interfingers with the oolitic limestone facies north of the Warm Springs Oil Fields. The sandstone facies is present sporadically but is included in Measured Section 2 (Plate III), as Js Unit 1. The platy facies was only found to occur on the eastern edge of the study area on the northeast flank of the Wild Horse Butte Anticline. The chert conglomeratic facies is made-up of chert pebbles that typically accumulate at the J_2 unconformity. They Originate from chert nodules that occur in the Gypsum Spring Formation. The interbedded sandstone and shale facies represents intertidal conditions on the flank of the Black Mountain High. The oolitic facies is

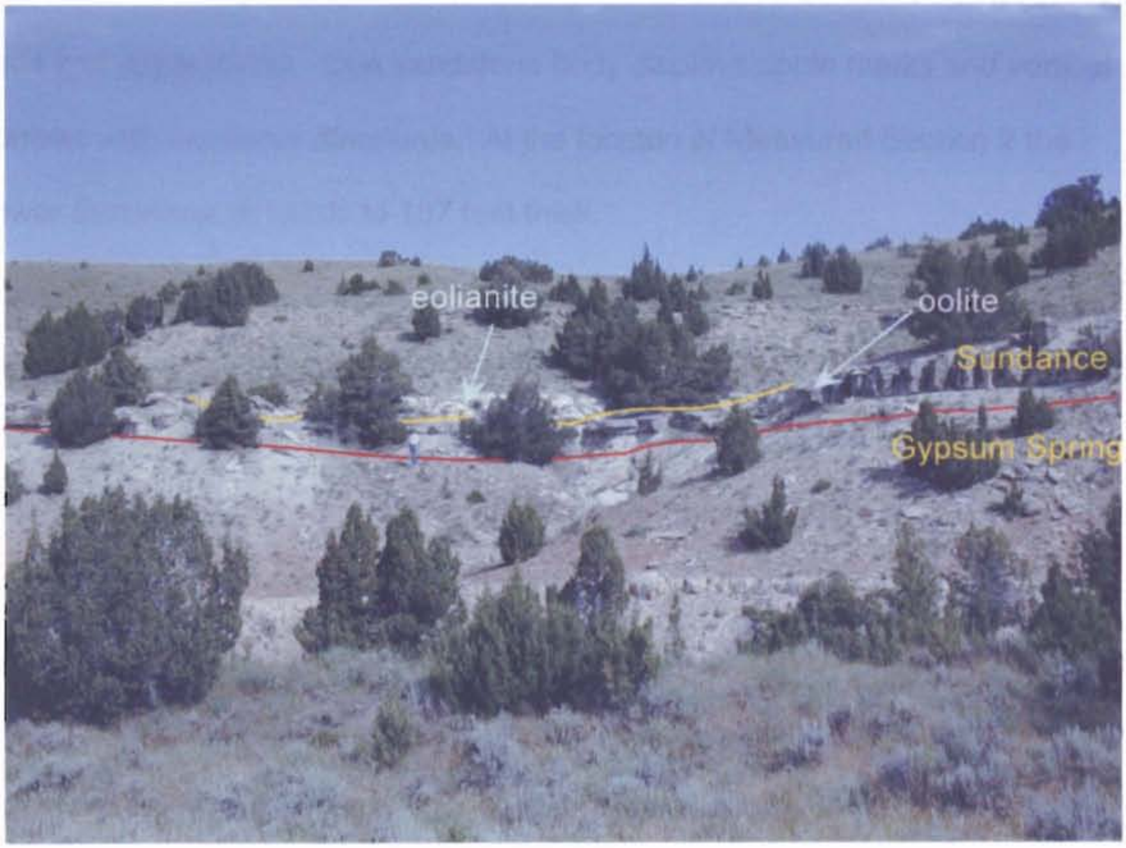

Figure 12. Interfingering of the oolitic limestone and eolian sandstone facies of the basal Sundance Formation. Outcrop located north of the W. Warm Springs Oil Field.

the most common, outcropping over most of the area (Figure 13). Above the oolite facies, the "lower" Sundance becomes relatively uniform throughout the area. The sequence leading up to the J_4 unconformity, which separates the "upper" from the "lower" Sundance, becomes interbedded clay shale, very fine sandstone and silty shale. The sandstone of this interval contains trough cross beds and ripple marks. One sandstone body displays ripple marks and vertical burrows with meniscus structures. At the locaton of Measured Section 2 the "lower Sundance amounts to 107 feet thick.

The boundary between "lower" and "upper" Sundance has been identified as the J_4 unconformity by previous authors. This surface represents erosion that occurred after the retreat of the "lower" Sundance sea due to the uplift of the Sheridan Arch (West, 1980). It is not clear how much of the section was lost to J_4 erosion in the Warm Springs Ranch study area. The transgression of the "upper" Sundance sea is not well evidenced by the lithology. The best indicators are the prolific occurrence of belemnite fossils and presence of glauconite in the clay shale above the contact. The "upper"/"lower" boundary was placed at the base of the belemnite-bearing interval. Evidence of an unconformity was not observed by the author at any horizon within the Sundance.

Above the belemnite unit the coarsening upward sequence of the "upper" Sundance becomes evident. Approximately 120 feet below the upper Sundance contact with the Morrison Formation, the marine shales become more resistant, forming near vertical outcrop. Within this interval sandstone and sandy shale interbeds appear that are burrowed and contain oscillation ripples on bedding

Figure 13. Oolitic limestone facies of the basal Sundance. Cross-bedding is visible. Pocket knife for scale. Outcrop located north of the West Warm Springs Oil Field.

planes. Molluscan shell hash occurs on some of the sandstone bedding planes. Some coquina flags are developed, made up of both intact and broken bivalve fossils. The frequency of the shell hash and coquina flags increases upward. The marine shale of the Sundance ends abruptly at the irregular contact with the upper glauconitic sandstone (Plate III, Measures Section 2). The irregular nature of the contact is due to the presence of load casts bulging into the underlying shale unit. Upward from the load casts, the sandstone displays abundant bimodal trough cross bedding. In the upper part of this unit, some herringbone cross bedding is present along with ripple marks and continued troughs. The uppermost unit of the Sundance is platy, friable, glauconitic, fine sandstone. This unit has a sharp, conformable contact with the Upper Jurassic Morrison Formation. The Sundance-Morrison boundary is marked by an abrupt disappearance of glauconite. The "upper" Sundance is 212 feet thick at the location of Measured Section 2.

The start of Sundance deposition in the study area is represented by four distinct facies, as mentioned previously. The oolite facies represents the existence of a shallow marine environment with agitated water conditions and strong bottom currents (Boggs, 1995). These conditions were probably a result of wave action as indicated by the presence of cross bedding in this unit at some locations. This facies interfingers with the cross-bedded sandstone facies. The presence of large-scale trough cross beds through most of this facies, as well as the exceptionally good sorting of the sandstone lead the author to interpret that an upper shoreface or, perhaps, eolian setting is the primary depositional environment for this facies (Figure 14). In the area of MS 2 (Plate III) this unit displays a decrease in size of trough cross beds in the upper part of the unit. This may indicate that the dune field was transgressed with marine waters, reworking some of the eolian sand in an upper shoreface setting for a short time. In the MS 2 area, the contact between the sandstone facies and the overlying clay shale is sharp, which would indicate a sharp sea level rise which ended conditions producing the shoreface environment.

The laminated platy facies, which occurs on the east edge of the area, accumulated in a lagoonal type of setting, where deposits were protected from wave influence (Figure 15). The laminated bedding, platy nature (splits easily along bedding planes) and lack of sedimentary structures are evidence for this interpretation. The only fossils found in this facies are rare fish scales. In all parts of the study area the basal facies is in sharp contact with the overlying clay shale, silty shale, and sandstone units of the "lower" Sundance.

Interbedding of facies in the "lower" Sundance indicates some sea level fluctuation. The ripple marked, vertically burrowed Js Unit 3 of MS2 (Plate III) may represent a shallowing to tidal conditions followed by a return to deeper marine silty shale deposition. This continued until the regression of the "lower" Sundance sea as indicated by the J_4 unconformity. Subsequently the surface was transgressed by the "upper" Sundance sea, thus covering the area in an open marine depositional setting. Abundant belemnite fossils in clay shale attest to open marine conditions.

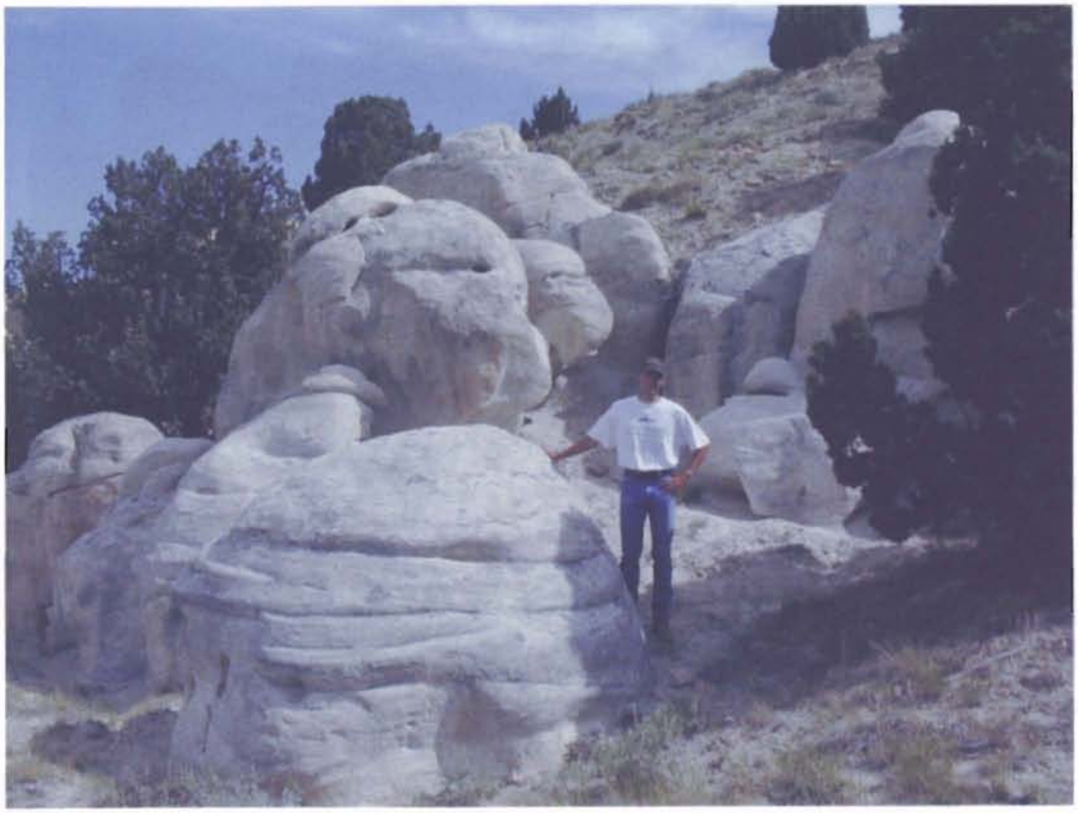

Figure 14. Eolian facies of the basal Jurassic Sundance Formation. Large scale wedge set trough cross-beds are visible. This outcrop is located just north of the East Warm Springs Oil Field.

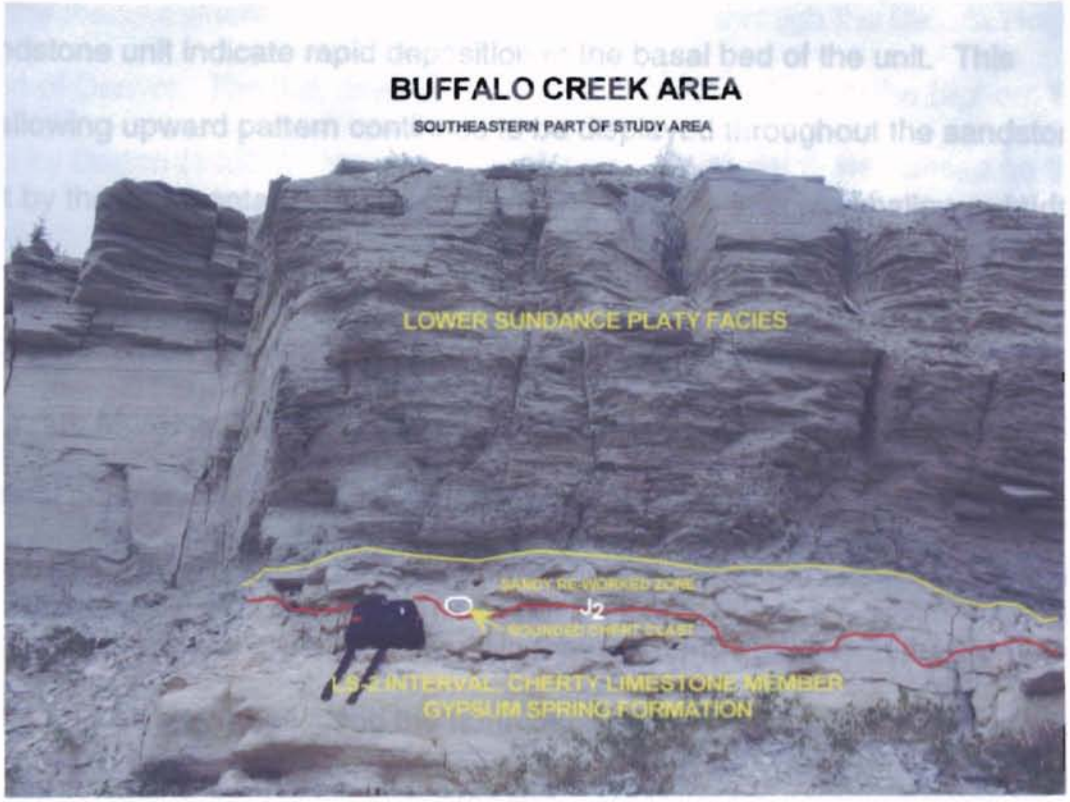

Figure 15. Platy limestone facies of the basal Sundance. This facies is limited to the far eastern part of the study area. Pack is approximately 6 inches tall.

The slow retreat of the "upper" Sundance sea is represented by Js Unit 6 of MS2 (Plate III). Coarsening upward of terrigenous clastic sediment size and increase upward of tempestite shell hash and coquina indicate steady shallowing upward through the section. Load structures at the base of the glauconitic sandstone unit indicate rapid deposition of the basal bed of the unit. This shallowing upward pattern continues to be displayed throughout the sandstone unit by the sedimentary structures. Bedding features indicate shallow subtidal conditons upward until Js Unit 8, where the sandstone becomes completely intertidal. When the Sundance sea no longer controlled sedimentation in the area, the Morrison sediments began accumulating conformably in continental, coastal plain environments, on top of the marine Sundance sediment.

Exposures of the Sundance Formation are numerous along the southern margin of the thesis area, particularly in the hills north above Buffalo Creek Road. Outcrop is also good all along the north flank of the Thermopolis Anticline and the north flank of the Red Spring Anticline. Topographic expression can be dramatic, where the upper glauconitic sandstone is sufficiently exposed. This unit typically forms a significant dull green cliff. Below this cliff there are steep shale slopes or low rounded hills, where the Sundance shale units outcrop over large area. Grasses are common growth on the more shaly outcrop, whereas the sandstones support sparse growth of cedars.

Morrison Formation

Eldrige named the Morrison Formation in 1896, for exposures near Morrison Colorado. Waldschmidt and LeRoy (1944) redefined the type section to be the roadcut where the Alameda Parkway passes through the Dakota Hogback west of Denver. The first description of Morrison rocks done in the Bighorn Basin was by Darton (1906a). His utilization of the Morrison name was based on the similarity between the interval he observed in Wyoming and the Morrison he had studied in Colorado. No formal subdivision has been applied to the Morrison Formation of the Bighorn Basin. The member names as they are defined in western Colorado and New Mexico do not extend into northern Wyoming. The Morrison lithofacies of the study area, like the Morrison elsewhere, are quite laterally variable. The most significant depositional systems observed within the thesis area are described below.

Morrison deposition began with the retreat of the “upper” Sundance sea. Terrestrial, coastal plain depositional environments accumulated on top of the underlying barrier island and tidal flat facies of the uppermost Sundance Formation. This produced a conformable contact, marked primarily by the disappearance of glauconite that is so prevalent in the "upper" Sundance Formation. Bjoraker and Naus (1996) measured six stratigraphic sections through the Morrison of the Warm Springs Ranch and divided the formation into three generalized informal units, based on a similar type of division done by Ostrom (1970). They identified a lower calcareous mudstone unit, a middle fine-grained, quartzose sandstone unit, and an upper calcareous mudstone unit with sandstone interbeds. This division best applies in the area of the Wyoming Dinosaur Center (WDC) dig sites and in the southwest corner of the thesis area where Bjoraker and Naus (1996) did their work. The application of these informal units becomes more difficult as one moves away from this part of the current study area. Depositional environments are seen in other parts of the area that are not present in the southwest part. The Morrison was measured and described for this work in the same area that Bjoraker and Naus (1996) conducted their study (Measured Sections 2 and 5, Plates III and VI) and their units are identifiable on the stratigraphic columns presented here.

The basal Morrison of MS 5 and MS 6 (Plates VI and VII) displays trough cross-bedded, very fine sandstone. This part of the Morrison at MS 2 (Plate III) is an interval of nonfissile mud shale with a few fine sandstone interbeds. Some of the interbeds contain trough cross beds. North of the dig sites, most notably on the north flank of the Thermopolis Anticline, the basal Morrison is expressed as a white, large-scale trough cross-bedded sandstone. This sand body has been called the Morrison "eolianite" by some previous workers (Figure 16). It was mentioned by Kvale (1986, p. 37) in his sutdy of the Morrison-Cloverly interval along the northeastern margin of the basin. It has also been identified on subsurface electric logs in regions north and northeast of the study area (D. Schmude, pers. comm.). Where the lower Morrison is occupied by sandstone, this lithology is followed by nonfissile mud shales and often with some sandstone interbeds. This description also applies to the basal Morrison in areas where the basal sandstones are not present.

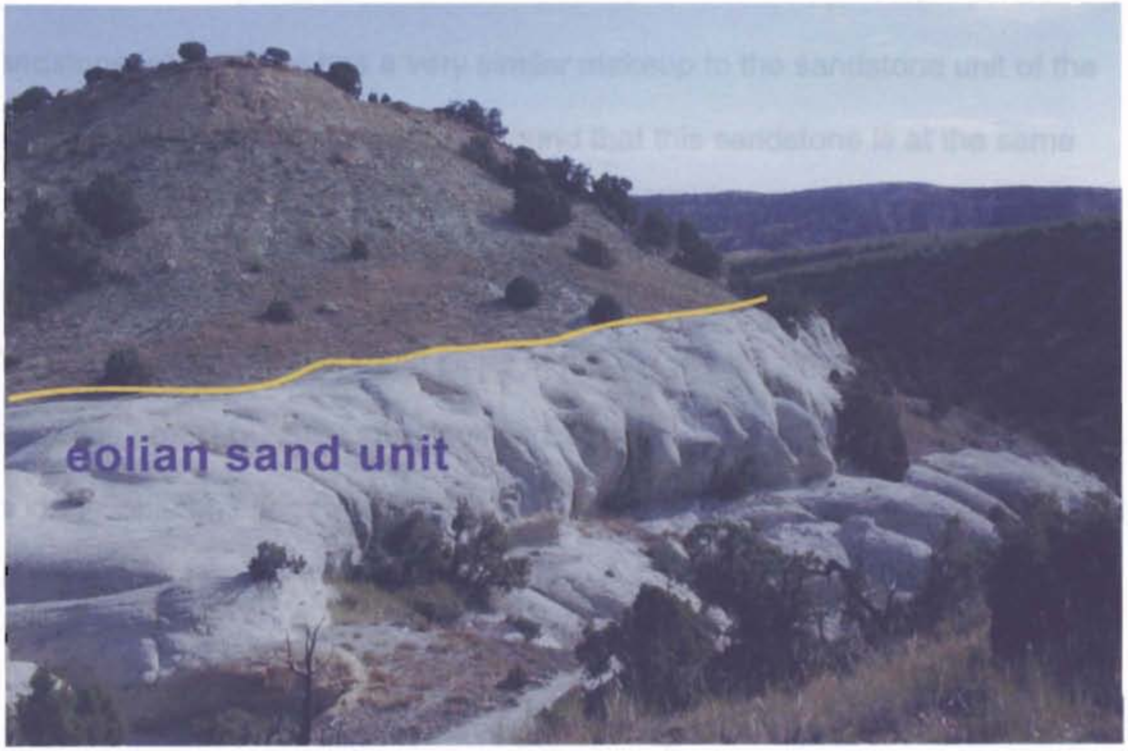

Figure 16. Morrison eolianite unit as seen in the northern part of the study area. This outcrop is located near the center of sec. 28, T43N, R94W

In most observed parts of the area, a trough cross-bedded, middle sandstone unit is present in the Morrison. This sandstone interval displays sedimentary structures indicative of fluvial channel deposits (Figure 17). Included in MS 5 (Plate IV) is an individual sandstone unit (Jm unit 7) within the sandstone interval that has a very similar makeup to the sandstone unit of the Bone Bed (BB) dig site. It was also found that this sandstone is at the same interval within the Morrison as the BB dig site. Workers for the WDC claim to have identified this same sandstone unit 0.25 mile to the south, where the Morrison outcrops on the south slope of the dig site hill above Buffalo Creek Road. Being of paleontologic significance, reasonably laterally continuous, and an identifiable unit separate from those directly adjacent to it, this sandstone unit will be referred to as the BB Sandstone for the remainder of this report.

Overlying the BB Sandstone is the upper calcareous mudstone interval. This lithofacies is present to some degree throughout most of the area, but are better observed at the WDC dig sites. For approximately 36 feet above the BB Sandstone the section contains an interval of mud shale interbedded with nodular limestones and marls. The carbonate-rich beds range from 5 to 9 inches thick (Figure 18). It is within this carbonate mudstone interval that the majority of the WDC dig sites have been discovered. Vertebrate fossil material has been found contained in both the carbonate-rich beds and the carbonate poor beds. In Jm Unit 8 of MS 5 vertebrate bone material was preserved in a very well indurated carbonate mudstone. Found in association with the bones of this interval are spherical calcite concretions approximately 3/8 inches in diameter,

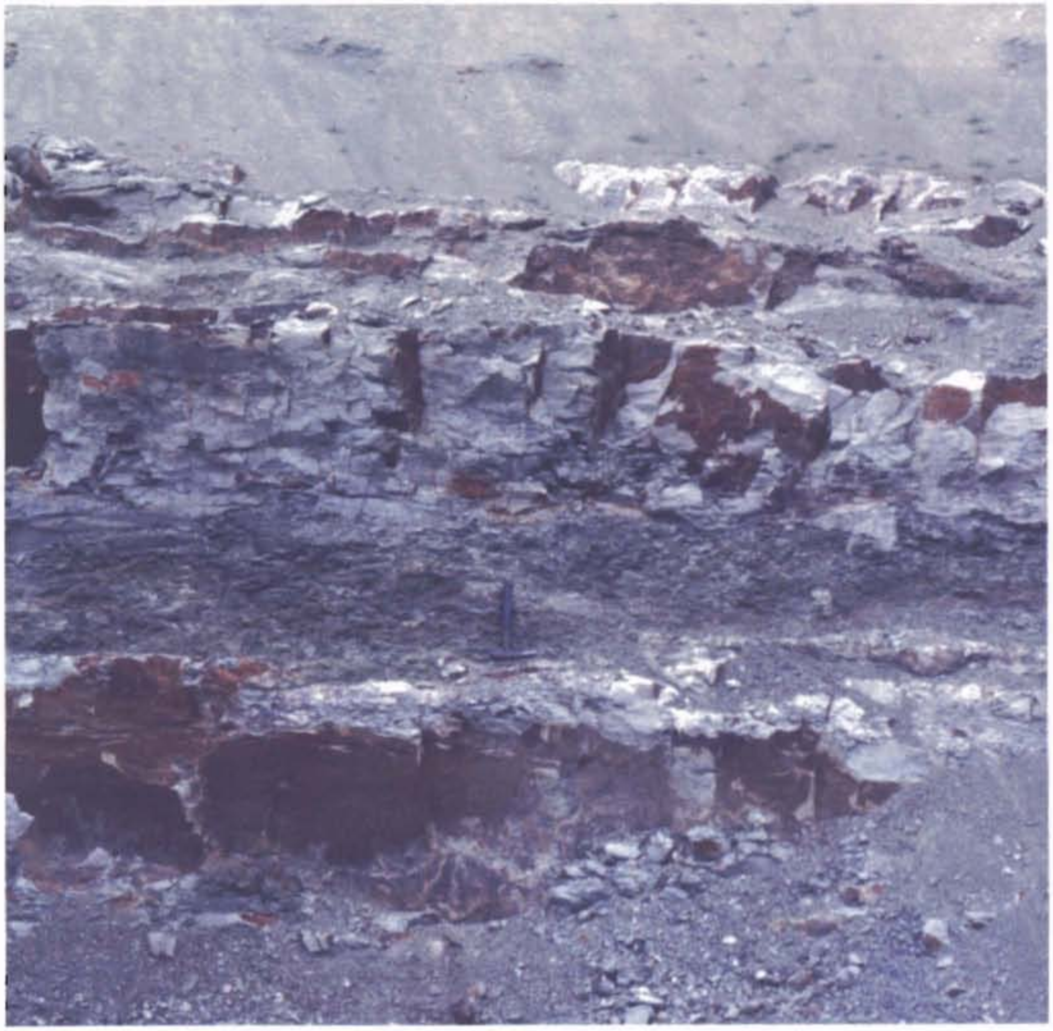

Figure 17. Lacustrine carbonate beds and interbedded mudstones of the upper Morrison Formation. Hammer near center of photo for scale. This outcrop is located at the Wyoming Dinosaur Center Digsite.

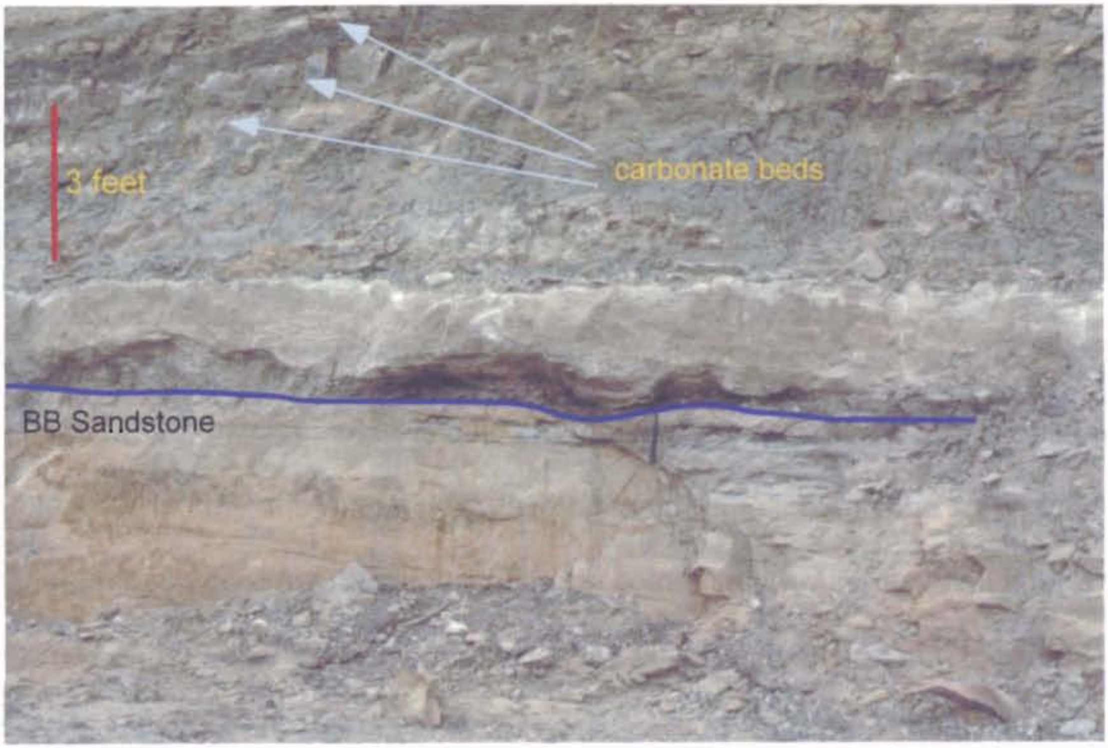

Figure 18. BB Sandstone below the upper calcareous mudstone interval which contains the nodular lacustrine carbonates.

that display radial structure. The origin of these spherulitic structures is not known. Coalified plant debris is also common in this interval. Occasional siltstone lenses are developed within the carbonate-poor beds. The carbonate-rich beds disappear vertically, rather abruptly, and overlying them are nonfissile mudstones with possible caliche nodules and glaebules occurring in the lower part of this unit.

The upper calcareous mudstone unit changes laterally into at least three other faces. Closest to the location of MS 5 (Plate IV) and visible from the dig sites is the channel sandstone facies (Figure 19). This facies is described as Unit 5 of MS 6. Its channel fill is a fine to medium-grained quartz-arenite with few visible sedimentary structures. It is developed at approximately the same interval as the upper calcareous mudstone. This, in combination with the close lateral proximity of the channel sandstone, leads the writer to conclude that the fossils of the WDC dig sites are located in facies genetically associated with this fluvial depositional system.

A relatively thick coal deposit occurs at near the same interval as the channel unit. The coal is seen several miles to the northeast of the channel outcrops on the north flank of the Thermopolis Anticline. The coal unit was not examined in detail by the writer but may provide a study topic for additional research. Further still to the northeast in the area of Wild Horse Butte, red bed shale and mudstone serve as the lateral equivalent of the coal and channel facies. The red beds are best demonstrated in sec. 34 of T 43 N, R 93 W.

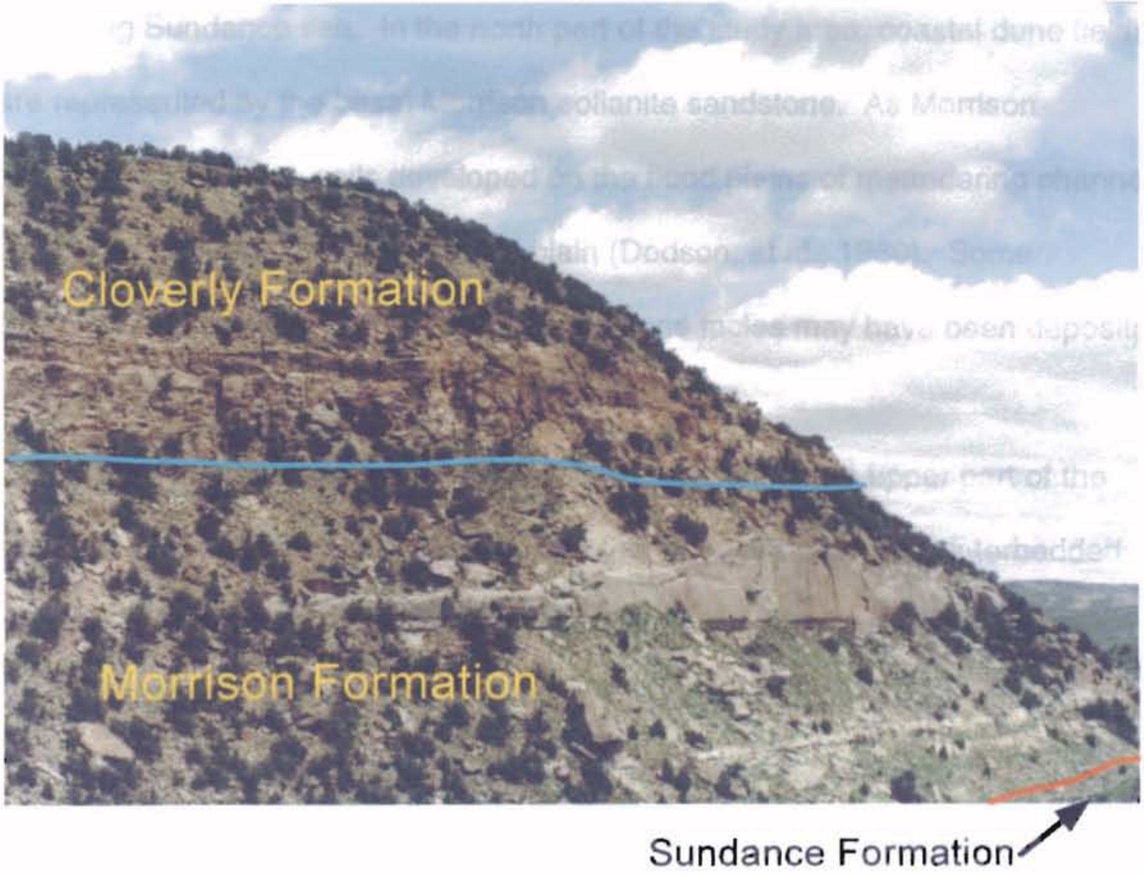

Figure 19. Morrison interval where measured for Section 6 (Plate VII). This outcrop is located approximately one mile northeast of the WDC digsites.

Regarding the geologic history of the Morrison, the first Morrison terrestrial sediments were deposited on top of tidal flat facies of the Sundance Formation. In the southern part of the study area, meandering channels were present in a broad flat alluvial plain and transported water and sediment to the northward retreating Sundance sea. In the north part of the study area, coastal dune fields are represented by the basal Morrison eolianite sandstone. As Morrison deposition continued, soils developed on the flood plains of meandering channel systems present in the lower coastal plain (Dodson, et al., 1980). Some carbonate elements of the calcareous mudstone facies may have been deposited in lakes on a fluvial floodplain.

The limestones, marls, and mudstones present in the upper part of the section are likely lacustrine in origin. The thin nodular carbonates interbedded with thin mudstones may lend weight to the idea of a seasonally alternating humid climate during Morrison deposition, as proposed by previous authors (Ostrom 1970, Dodson et al., 1980). Aquatic plants can cause calcite to precipitate by removing carbon dioxide from fresh water. If a yearly or seasonal climatic fluctuation modified the rate or amount of photosynthesis by aquatic plants, particularly blue-green algae or planktonic algae, this would affect the amount of carbonate produced in a lacustrine setting (Boggs, 1995). These lakes formed probably seasonally on a broad, low relief floodplain that also contained swamps and were dissected by river channels. Plant life was abundant, as is shown by the development of coal deposits, and the abundance of coalified plant material in the BB Sandstone and units directly above. As the lakes, ponds and swamps dried up during more arid climatic episodes, soils developed.

Due to the irregularity of the contact, it is uncertain as to how much time was lost due to the erosional unconformity at the Cloverly-Morrison boundary. The contact is marked by an abrupt change to the conglomeratic sandstone units of the basal Cloverly. These conglomerates represent braided stream deosits, a depositional style not seen in the Morrison of northwestern Wyoming (Figure 20).

The Morrison Formation has widely distributed outcrops throughout the area, typically occurring on south facing slopes beneath a bluff of lower Cloverly conglomerate. The best vertical exposure of the interval is where it has been cut for the extraction of vertebrate fossils by the WDC. Good Morrison Formation outcrop occurs all along the north flank of the Thermopolis Anticline, and on the Red Spring Anticline. Where measured in the southwestern part of the study area the formation shows some variance in thickness. At the location of Measured Section 2 the Morrison was found to be 236 feet thick. At MS 5 the formation measured 208 feet thick, and at MS 6 186 feet thick. The Morrison in the area is known for its prolific growth of cedar trees and support of grasses on the more muddy portions of the interval.

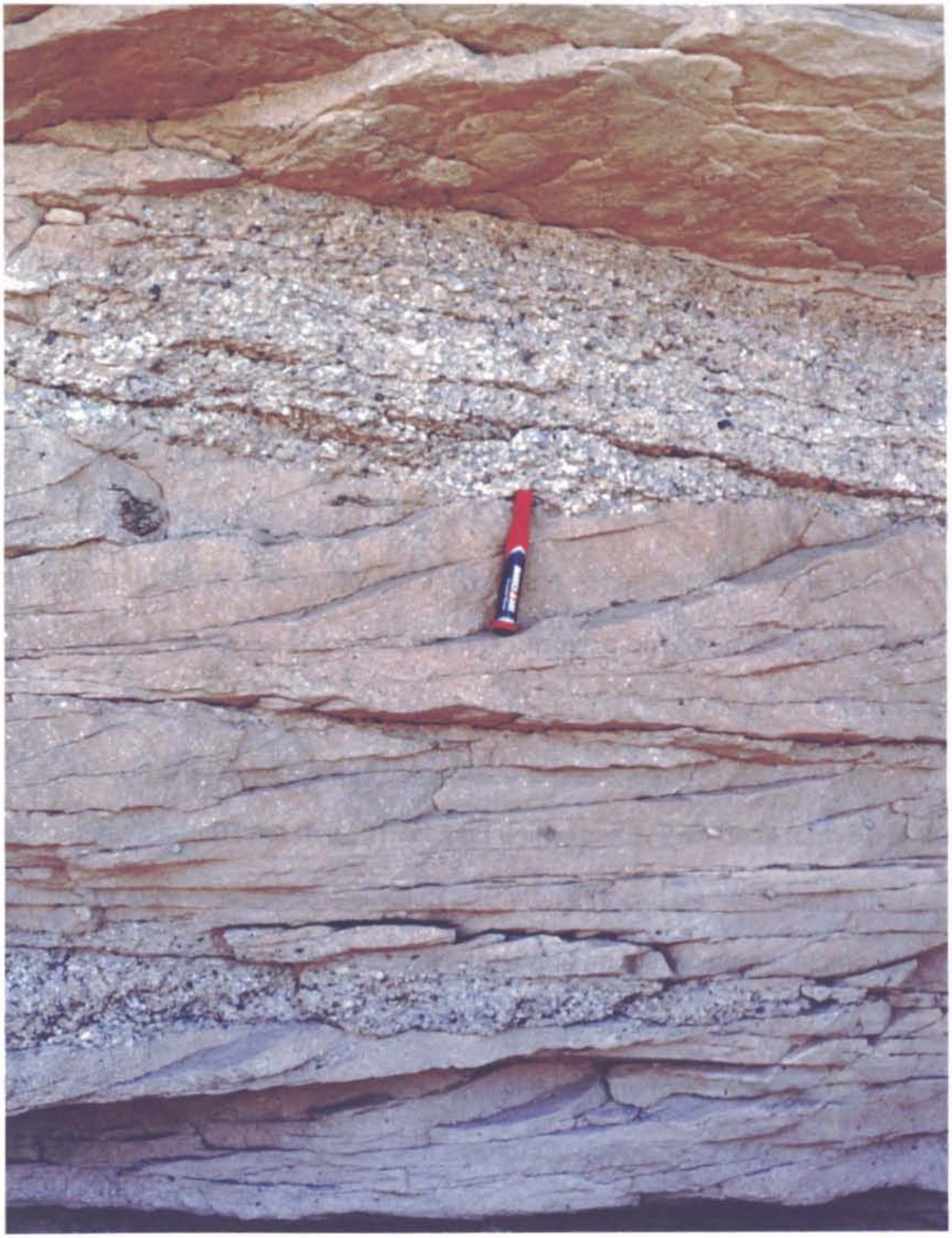

Figure 20. Trough cross-bedded, conglomeratic sandstones of the basal Cloverly. Marker is approx. 5 inches long.

Cretaceous System

Cloverly Formation

The Cloverly Formation was first defined by Darton (1904) for an interval of conglomeratic sandstone and mudstones overlying the Morrison on the east side of the Bighorn Basin. The interval of sandstone, siltstone, and marine shale above the presently-constituted Cloverly Formation has, at times, been included in the Cloverly by some authors. They termed this upper interval the "Rusty Beds". In this report the upper Cloverly contact is placed at the top of the highest nonfissile mudstone unit, below the Rusty Beds. The "Rusty Beds" of this report are separated out as the Sykes Mountain Formation based on stratigraphic position and nature of the upper and lower contacts.

The Cloverly Formation of the study area typically invloves a lower conglomeratic sandstone unit. This basal unit varies in thickness form 50 to 90 feet. In the area of Measured Section 3 (Plate IV) it can be separated into a lower chert pebble conglomeratic sandstone and an upper nonconglomeratic sandstone. Both intervals display abundant large-scale trough cross bedding. The local increase in thickness of this unit may be due to greater incision into the Morrison by the fluvial processes that eventually deposited the conglomerate. In some locations mud drapes and mud rip up clasts are present in the base of the conglomeratic sandstone.

In sharp contrast to the basal conglomeratic sandstone is the ovelying interval of red, nonfissle mudstone (Figure 21). At the location of Measured

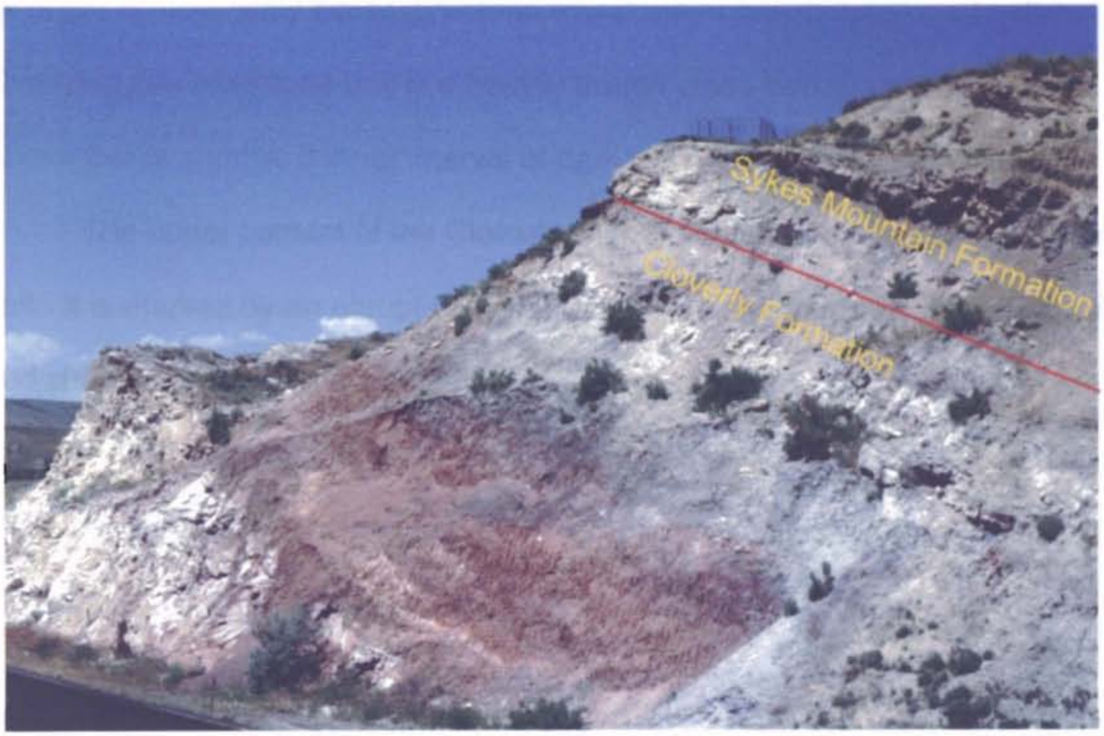

Figure 21. Cloverly nonfissile mudstone interval. Basal conglomerate visible on left, and Sykes Mountain Formaiton visible on upper right. This roadcut is located approximately 3 miles north of Thermopolis on U.S. Highway 20.

Section 3 (Plate IV) this interval contains at least one interbedded sandstone body that laterally develops into a fluvial deposit that scoured into the underlying sandstone unit. Some carbonate debris was found weathering out of the slope. Its origin is most likely either lacustrine limestone or a well-developed caliche. Overlying this mudstone unit is a heavily trough cross-bedded sandstone unit. Above this is another thinner interval of dark red nonfissile mudstone.

The upper contact of the Cloverly occurs at the top of the upper mudstone unit. It is marked by an abrupt facies and color change to gray, marine siltstone and shale. It is likely that when the Cloverly was transgressed by the Cretaceous sea that deposited the Sykes Mountain, some erosion occurred at least as a revinement surface. The contact does not appear to be irregular and it is unknown to what degree the contact is unconformable in this area.

The lower sand and conglomeratic sandstone units of the Cloverly represent deposition in braided streams, possibly on a braid plain or alluvial fan. Locally, in the area of Measured Section 3 (Plate IV) there was better channel development and incision. When braided stream deposition ended, soils developed on the alluvial fan. During this time small stream channels were present and possibly lakes as well. Larger-scale channel deposition resumed throughout the area, as seen with the upper sandstone unit. Soils again developed above these upper channel deposits until they were transgressed by the oldest element of the Cretaceous interior seaway, which initiated deposition of the Sykes Mountain Formation. The thickness of the Cloverly Formation was found to be 384 feet at the location of Measured Section 3. Aside from the basal conglomeratic unit, Cloverly outcrop is poor in most of the study area. The lower unit, however, caps many hogbacks and some of the highest points of the area. The best Cloverly exposure is in the slope along Carter Ranch Road and in the north flank of the Red Spring Anticline.

Sykes Mountain Formation

The Sykes Mountain rock units are the first representation of Cretaceous marine transgression of the area. This formation was first separated from Darton's (1906a) Colorado Formation by Washburn (1908). Washburn referred to thinly bedded sandstone and shales of the Lower Colorado Formation as the "Rusty Beds" due to the abundant limonitic concretions in the unit. They were interpreted as indicating the basal transgressive unit of the Cretaceous interior seaway (Minielly, 1998). Washburn also proposed the presence of an unconformity at the base of the Rusty Beds. When Lupton (1916) defined the Thermopolis Shale, he included all sedimentary rocks from the top of the Cloverly to the base of the Mowry Formation. Lupton justified grouping the Rusty Beds with the Thermopolis due to the gradational nature of the contact between the two intervals. Moberly (1956, 1960, and 1962) established the current stratigraphic terminology used in the basin. In his 1960 work he first proposed the name Sykes Mountain Formation for the Rusty Beds. The first modern, detailed work completed on the sedimentology of the formation was carried out by Soliman (1988).

The lower contact of the Sykes Mountain is marked by an abrupt change from the nonmarine facies of the Cloverly to various marine facies of the Sykes Mountain (Figure 22). Ostrom (1970) placed the contact based on a change from parallel laminted gray shale to the blocky and variegated mudstones of the Cloverly. The contact is generally considered to be unconformable.

Previous authors have cited the presence of marine facies in sharp contact with subjacent nonmarine facies and thus interpreted erosion to have occurred at the contact. The Sykes Mountain facies directly above the contact are not the same throughout the area. In the southern part of the study area, at Measured Section 3 (Plate IV), a sharp change occurs from the blocky dark red to maroon mudstones of the Cloverly to fissile shales and siltstone of the Sykes Mountain. In the northwest part of the study area near Measured Section 4 (Plate V), the contact is marked by an abrupt change from the Cloverly mudstones to a tabular-planar cross-bedded sandstone body in the Sykes Mountain Formation. With both areas the Sykes Mountain displays one prominent sandstone body that is cross-bedded, has asymmetric ripple marks on bedding planes, and sometimes contains hummocky cross bedding. Directly above this sandstone is clay shale that appears to coarsen upward into burrowed siltstones. Two to four of these relatively short coarsening upward sequenced are typically present.

The upper Sykes Mountain contact is difficult to determine precisely. It is generally considered to be gradational and conformable. Moberly (1960) placed the contact at the top of the uppermost siltstones. This location of the contact is

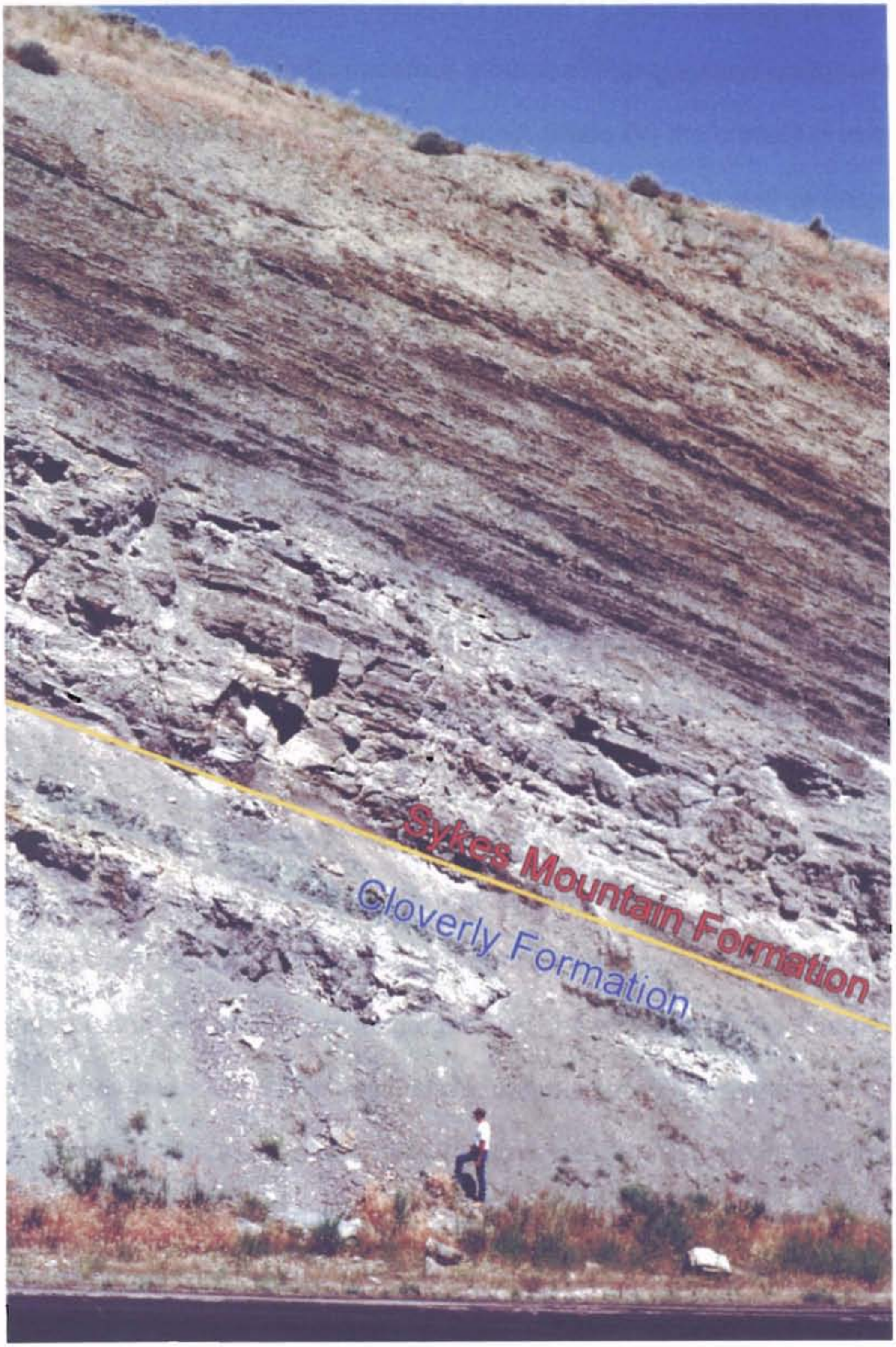

Figure 22. Contact between the Cloverly and Sykes Mountain Formations shown by the yellow line. The contact is placed on top of the last nonfissile reddish mudstone. Approximately 3 miles north of Thermopolis on U.S. Highway 20

feasible in the area of Measured Section 4 (Plate V), where shortly above the uppermost siltstone, the shale becomes a much darker gray and consistently a clay shale. In the area of Measured Section 3 (Plate IV) the contact is more difficult to place. The coarsening upward sequences are less well developed. The gradation from Sykes Mountain to Thermopolis occurs over a relatively large interval here. The contact is placed approximately in the location were the shale changes from dominantly medium to light gray and brown and silty, to dark gray, clay shale.

As stated earlier, the Sykes Mountain represents the first transgression of the Cretaceous interior seaway into northwestern Wyoming. This formation shows evidence of deepening into the Thermopolis Shale. The mud drapes, burrowing, and cross bedding in the sandstone bodies indicate a tidal origin (Boggs, 1995). The transition to clay shale above the sandstone body and individual siltstone beds indicate a rather abrupt deepening at the top of the sandstone. Above the sandstone a few shallowing upward cycles are evident as sediment becomes more coarse upward through each cycle. When coarse sediment (sand and silt) are no longer present, the transition to the Thermopolis shale is complete. The Sykes Mountain is approximately 90 feet thick.

The best exposures of the Sykes Mountain Formation are in the hills on the north side of Carter Ranch Road, and in its outcrop area north of the Lucerne Anticline and north of the Red Spring Anticline (Plate I).

Thermopolis Shale

Lupton (1916) first applied the term Thermopolis Shale to the strata between the Cloverly and Mowry Formations. Darton (1904) had previously assigned these strata to the Benton Formation. Darton (1906a) reassigned them to the Colorado Formation. Lupton's (1916) subdivision of the Colorado became the Thermopolis, Mowry, and Frontier Formations. Lupton's (1916) Thermopolis Shale included the Rusty Beds, which were broken out later by Moberly (1960) as the Sykes Mountain Formation. Hewett and Lupton (1917) named the Muddy Sandstone unit, which occurs near the middle of the Thermopolis Shale.

As previously discussed in this chapter, the contact between the Thermopolis Shale and the underlying Sykes Mountain Formation is difficult to place due to its gradational nature. This contact represents a deepening from the shallow marine conditions responsible for Sykes Mountain deposition, to the deeper, more open marine environments, where the Thermopolis accumulated. The Thermopolis Shale is made up of thick, dark gray shale units that are separated near the middle by the Muddy Sandstone Member. The Muddy Sandstone is a quartz-arenite with planar cross bedding, some plane bedding and some asymmetrical ripples. The member is heavily burrowed both horizontally and vertically.

The majority of the Thermopolis represents open marine to deep marine deposition. A shallowing occurred during the time of Muddy Sandstone deposition. Based on the abundant sedimentary structures described earlier the Muddy is interpreted to have been deposited in a subtidal to intertidal setting

(Boggs, 1995). The base of the Muddy in parts of the Wind River and Powder River basins is erosional. Hence it is likely that the base of the Muddy Sandstone is a disconformity surface everywhere in northern Wyoming. Following the Muddy there is a return of open to deep marine sedimentation as was seen below the Muddy. The upper contact of the Thermopolis is gradational in to the Mowry Shale. The Thermopolis Shale was found to be 495 feet thick at the location of MS 4. Topographic expression of the Thermopolis is generally that of a low-lying, flat valley floor. The Muddy Sandstone does generate small hogbacks in areas where it is sufficiently thick. The Thermopolis is usually well grassed with no trees, but abundant sage.

Mowry Shale

Lupton (1916) defined the Mowry Shale Formation at the same time as the Thermopolis and Frontier Formations. The Mowry is bounded on the bottom by a gradational contact with the Thermopolis Shale (Figure 23). The upper boundary between Mowry and Frontier formation is placed at the Clayspur Bentonite (Figure 24). The Clayspur separates the Mowry from the first of the coarsening upward sequences of the Frontier Formation. The transition from Thermopolis to Mowry is marked by coarsening of the sediment from clay to silty clay and silt. The Mowry is also significantly more indurated than the Thermopolis. The slope of the Mowry is banded in light and dark stripes. The darker colored intervals tend to be slightly silty, clay shale with abundant fish scales; these grade into the lighter interval which tends to be more silty, more resistant, and iron stained with

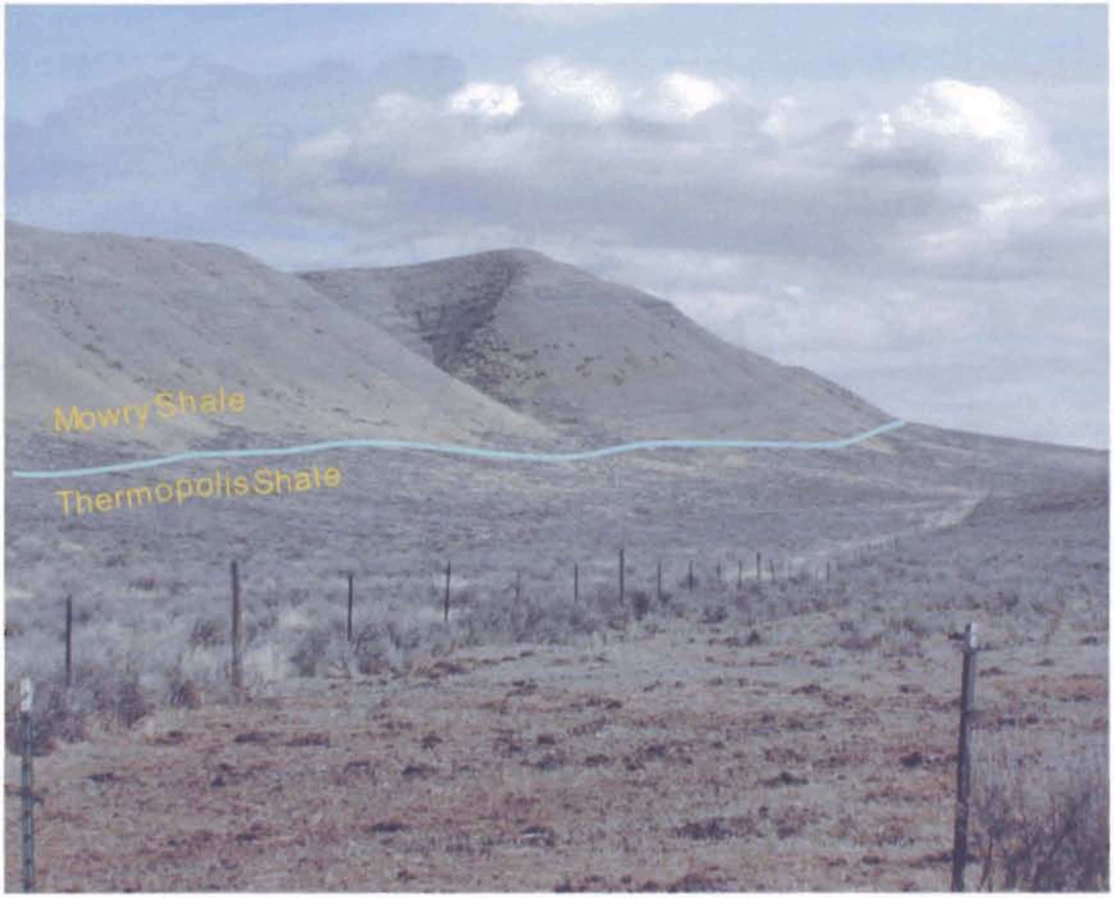

Figure 23. Approximate contact betwee the Thermopolis Shale and Mowry Shale. The upper part of the Thermopolis Shale forms valley floors and is rimmed by the more resistant Mowry Shale. Outcrop located on the north flank of the Red Spring Anticline.

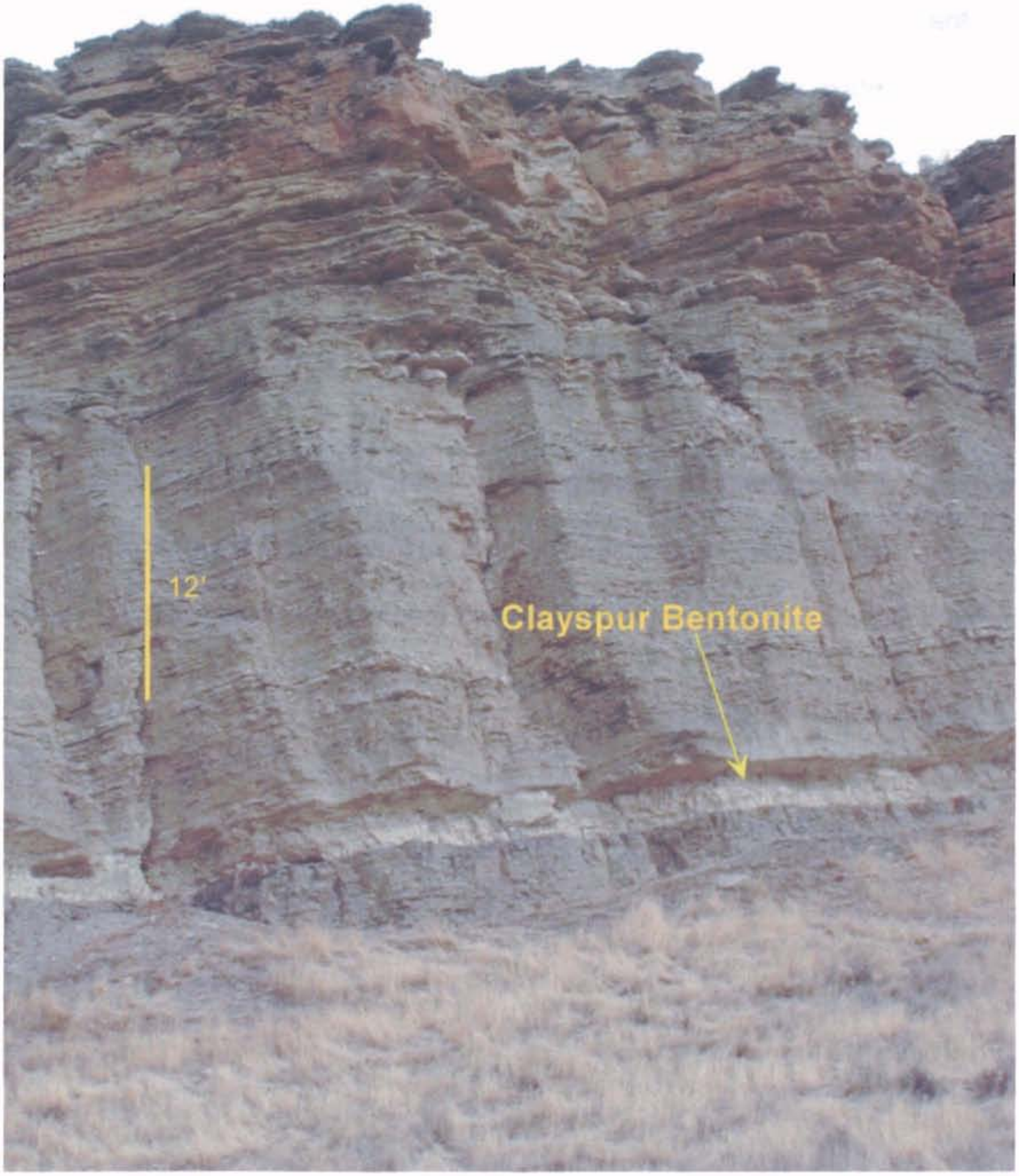

Figure 24. Clayspur Bentonite marks the upper contact of the Mowry Shale Formation. The first coarsening upward sequence of the overlying Frontier Formation can be seen capping the hill. Outcrop located approximately 4.5 miles north of Thermopolis on East River Road.

rare fish scales. Near the top of the Mowry definite siltstone beds appear that contain burrows.

The Mowry overall represents a time of mild sea level fluctuation, This is indicated by the alternating intervals of dominantly clay shale with abundant fish scales, which grade into more silty intervals. The upper Mowry evidences a more drastic fluctuation as shown by the better-developed siltstone beds and fish-scale-rich, clay shales representing shorter intervals. Some of the siltstones may have been deposited as shallow as in the intertidal zone as evidenced by the presence of mud drapes. The Mowry thickness at the location of MS 4 is 384 feet.

The Mowry of the study area is not vegetated, probably partially due to the steep slope where it crops out. The Mowry forms a significant hogback along the north edge of the study area, where exposures are the best and most complete.

CHAPTER III

STRUCTURAL GEOLOGY AND TECTONIC INFLUENCES

Development of the Bighorn Basin

The Bighorn Basin is an asymmetric, intermontane basin of the Rocky Mountain foreland. The tectonic history of the Bighorn Basin is highly complex due to various tectonic and sedimentary events that took place during the Cordilleran and Laramide orogenies.

The Bighorn Basin, like most other Rocky Mountain basins, developed along faults and zones of weakness in basement rocks, associated with the many previous mountain-building episodes that had occurred on the western part of the craton (Haun and Kent, 1965). The basin as we know it today developed during the Laramide Orogeny of Late Cretaceous and Early Tertiary time. The basin trends northwestward, is ovate, and is bounded by the Bridger Range, and Owl Creek Mountains to the south, the Absaroka and Beartooth Ranges to the west, and the Pryor and Bighorn Mountains to the east and northeast (Figure 25). The northernmost boundary is formed by the Nye-Bowler lineament, a folded and faulted zone in southern Montana. The basin is approximately 120 miles long and 90 miles wide at its broadest point. The Bighorn Basin can be classified based on Dickinson 1974 basinal classification as a Foreland Intermontain Basin (Dickinson, 1974). Many of the Rocky Mountain Laramide basins are defined likewise. The Miall basin classification would categorize the Bighorn Basin as a Foreland Basin (Miall, 1990).

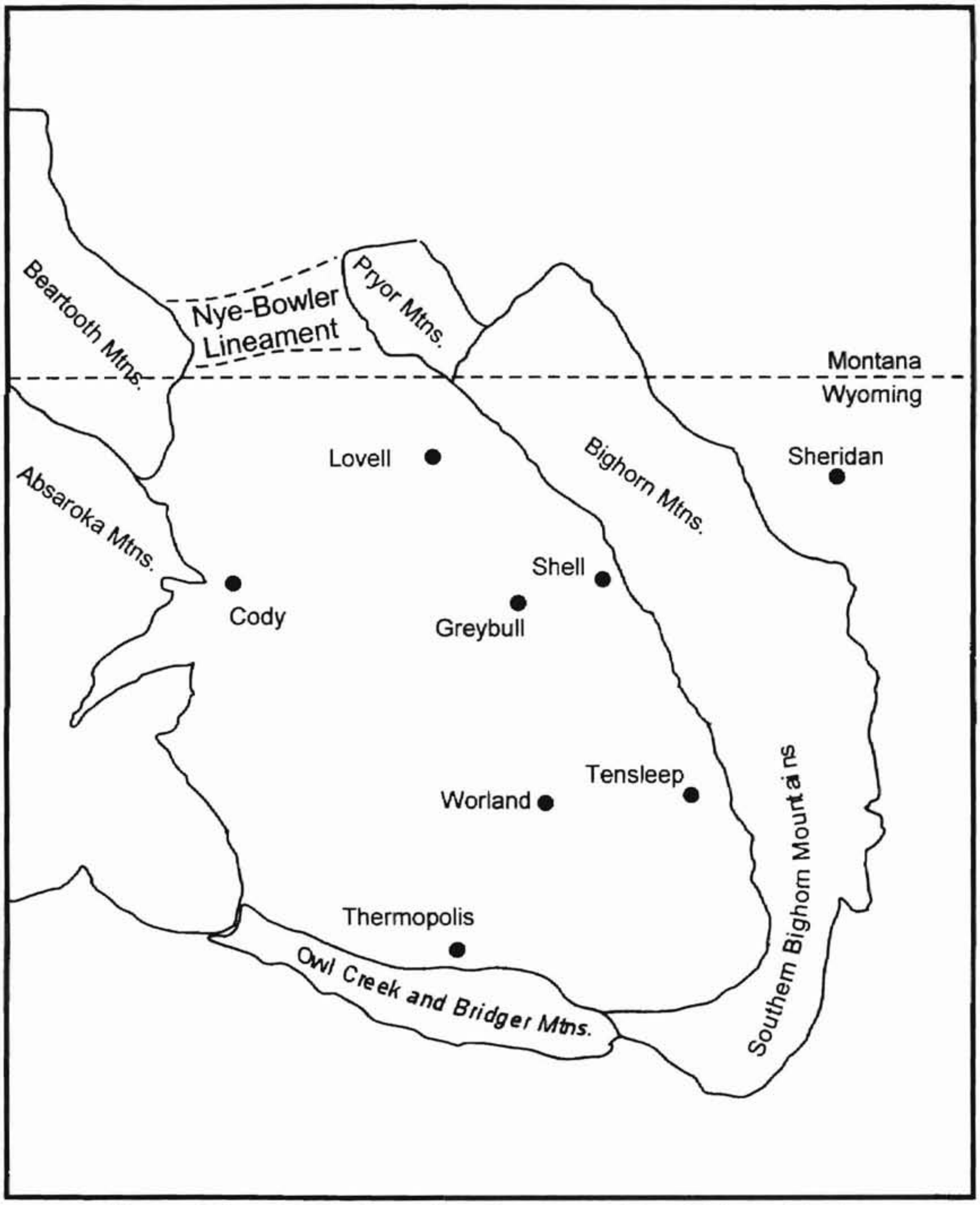

Figure 25. Major bounding features of the Bighorn Basin

The Laramide Orogeny, the last major mountain building episode to affect the area, was most intense in northern Wyoming during the Paleocene Epoch. This is when the peripheral mountain uplifts began rise. Many new anticlines were developed and older structures underwent additional uplift. It was during this time that the Nye-Bowler lineament developed (Thomas, 1965). According to Curry (1983) the mode of mountain formation in the Bighorn Basin did not involve direct uplift, but instead vertical rotation of large crustal plates. This caused rotation and tilting of smaller crustal blocks as faulting proceeded. The upward rotation of these smaller crustal blocks generated the mountain uplifts and peripheral structures (Curry, 1983).

Uplift and folding continued at least into the Eocene, giving rise to low angle thrusts or decollment surfaces in the Absaroka and Beartooth Mountains. Large blocks of Paleozoic rocks were thrust many miles toward the center of the basin (Thomas, 1965). Blocks containing Ordovician, Devonian, and Mississippian rocks, such as the Heart Mountain Block northeast of Cody, are estimated to have moved from 28 up to 48 miles (Pierce, 1941). During the Eocene, the mountain ranges were 3000-5000 feet above the basin floor. Volcanic material produced by activity in the Absaroka Volcanic Field added elevation to the rising mountains that lined the western side of the basin as well as contributing volcanic sediment to the basin interior (Thomas, 1965). Erosion removed most of the redeposited volcanic sediment and developed the present topography.

Structural features of the Warm Springs Ranch area are typical of those elsewhere along the southern margin of the Bighorn Basin. The area contains all or parts of four named anticlines and one large-scale named fault (Figure 26). These structures are the Thermopolis, Lucerne, Red Spring, and Wild Horse Butte anticlines and the Red Spring Fault. Each anticline has been explored for hydrocarbons and has produced commercial amounts of oil and gas.

Thermopolis Anticline

Only the east half of the Thermopolis Anticline occurs in the study area (Figure 26). Trending eastward through the central part of the area, this structure contains both the East and West Warm Springs Oil Fields. The Thermopolis Anticline is markedly asymmetric. Like most other structures in this part of the basin, it has a steeply dipping southern limb. The oldest rocks exposed in the structure are birdseye limestone in the uppermost Phosphoria Formation. These crop out along the axis of the anticline, located within the boundaries of the Hot Springs State Park. Near the axis of the anticline, at Hot Springs State Park adjacent to the Bighorn River, is the site of the hot springs. Although no faults are evident at the surface, the anticline is probably faulted, allowing the release of hot, sulfurous water (Hewett and Lupton 1917). Flat-lying travertine has been precipitated on several of the Mesozoic rock units.

Beds on the northern limb of the Thermopolis Anticline have a relatively gentle dip of 7° to 13°. The southern limb has a significantly steeper dip of approximately 61° (Figure 27). Paylor et al. (1989) described the stratigraphic

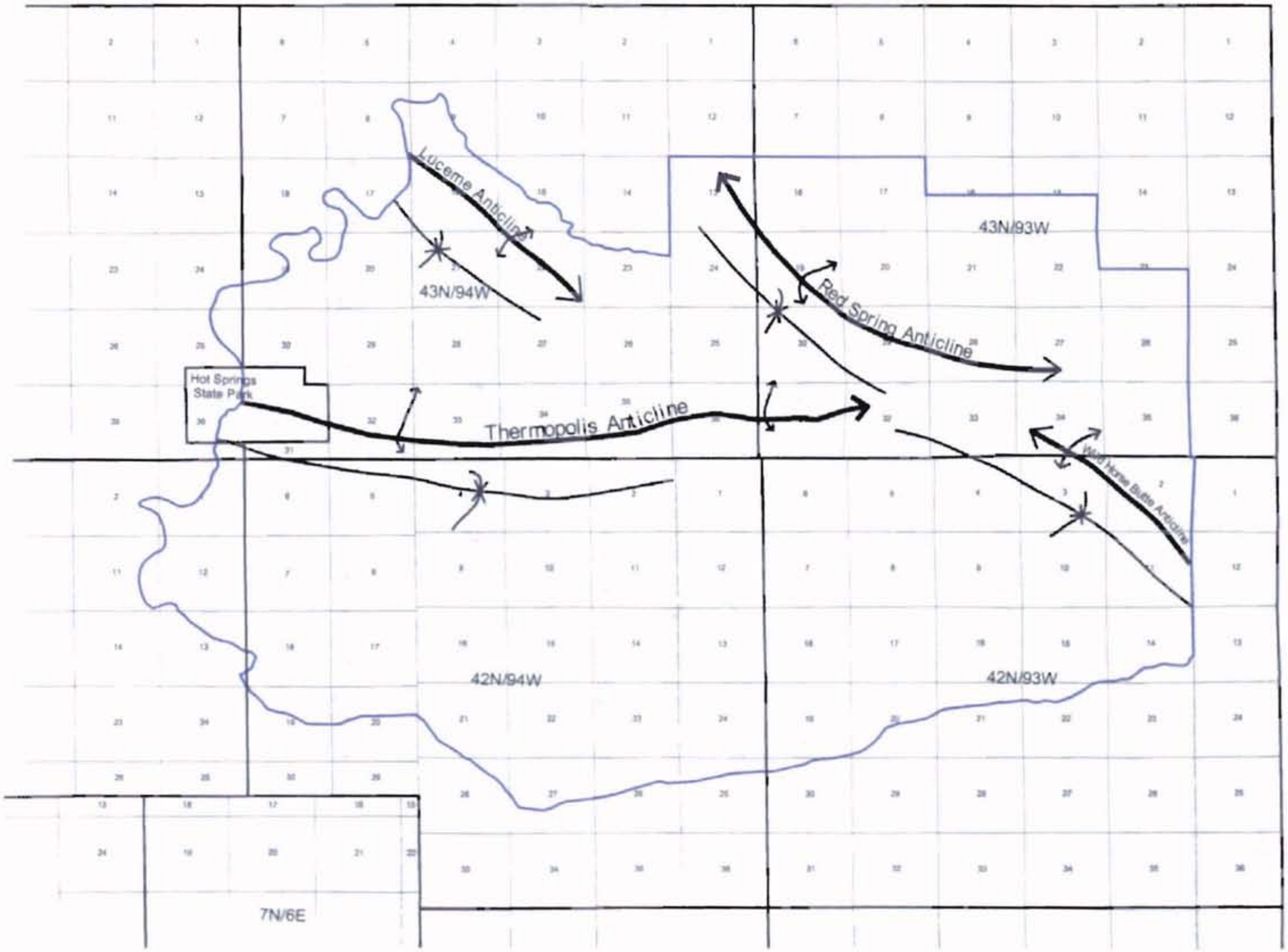

Figure 26. Major anticlines in the study area. Shown are major anticlines (named) and synclines.

sequence on the southern limb as being about 25% thinner than that on the northern limb. They also reported finding no thickening of ductile units along the hingeline of the fold. Seismic data from west of the Bighorn River was presented by Paylor et al. (1989). These data were interpreted by those authors to indicate that the hinge of the syncline to the south of the Thermopolis Anticline is faulted. Based on that interpretation, it is reasonable to believe that faulting has occurred along the synclinal hinge in areas east of the Bighorn River as well.

Lucerne Anticline

Most of the other anticlines in the study area are smaller than the Thermopolis Anticline. The Lucerne Anticline (Figure 26) is smaller; only the eastern end extends into the northwest corner of the thesis area. A sag in the northwest-plunging fold near the town of Lucerne creates a feature known as the Gebo Dome to the west of the Bighorn River. Perhaps this sag in the Lucerne Anticline has influenced the course of the Bighorn River. This structure, like other anticlines in the area, shows steeper dips on its southern limb (Figure 28). Dip on the south limb ranges from 31°-38°, compared to dip of the northern limb, which ranges from 15°-24°. The oldest rocks exposed in the anticline within the study area are of the Morrison Formation. Hydrocarbons are produced from the anticline.

Figure 27. View of the Thermopolis Anticline looking eastward. The more steeply dipping Gypsum Spring and Morrison Formations of the south flank can be seen on the right. The less steeply dipping Chugwater and Gypsum Spring Formation of the north flank can be seen on the left of the photograph. The hill in the foreground is capped by Quaternary Travertine originating from the hot springs.

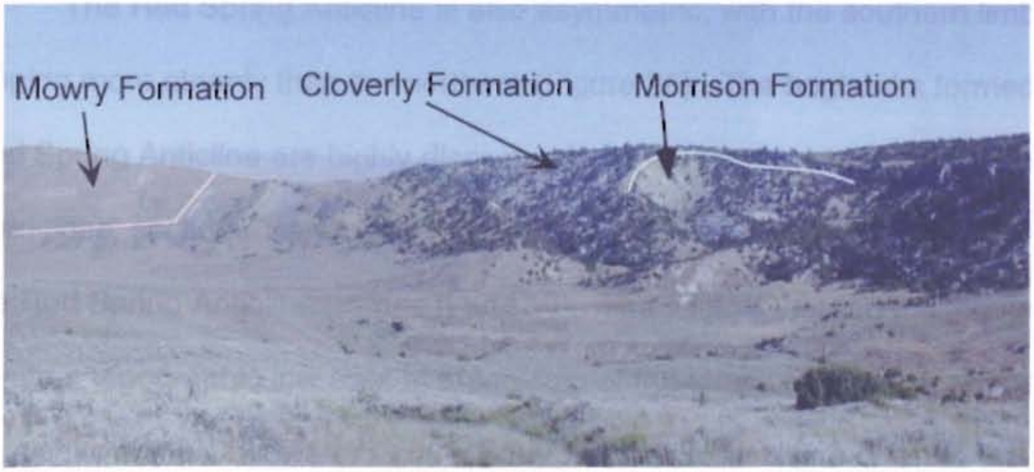

Figure 28. View looking toward the northwest of the Lucerne Anticline. Cloverly can be seen arching over the green mudstones of the Morrison in the exposed core of the structure. On the left of the photo the sharp change in dip may be seen in the light colored beds of the Mowry.

Wild Horse Butte Anticline

Near the eastern edge of the study area is the Wild Horse Butte Anticline (Figure 26). This feature has been referred to as "a wrinkle" by Hewett and Lupton (1917). This is a tight fold, expressed as a topographic high, on the eastern slope of Wild Horse Butte (Figure 29). The fold is wider near the valley of Buffalo Creek, where the north limb trends southeastward and the south limb bends westward paralleling Buffalo Creek and the Bridger Mountains. In total, the anticline is approximately five miles long, asymmetric, with a steep-dipping south limb. The axis of the Wild Horse Butte is nearly parallel to that of Red Spring Anticline.

Red Spring Anticline

The Red Spring Anticline is also asymmetric, with the southern limb dipping more steeply than the northern (Figure 26). The hogbacks formed by the Red Spring Anticline are highly dissected by streams. As a result of these conditions, sections 1 and 4 were measured in the hogbacks on the north flank of the Red Spring Anticline (Plates II and VI). The valleys that breach the anticline create a topographic low area in the middle of the structure which is rimmed by hogbacks of the Chugwater Group, prompting the local name given to the feature of The Red Hole (Figure 30).

Dip measurements taken on the north limb range from 15° to 22°, whereas on the south limb dips were measured from 28° to 52°. A distinctive characteristic of this and other synclines in the area, which was also noticed by

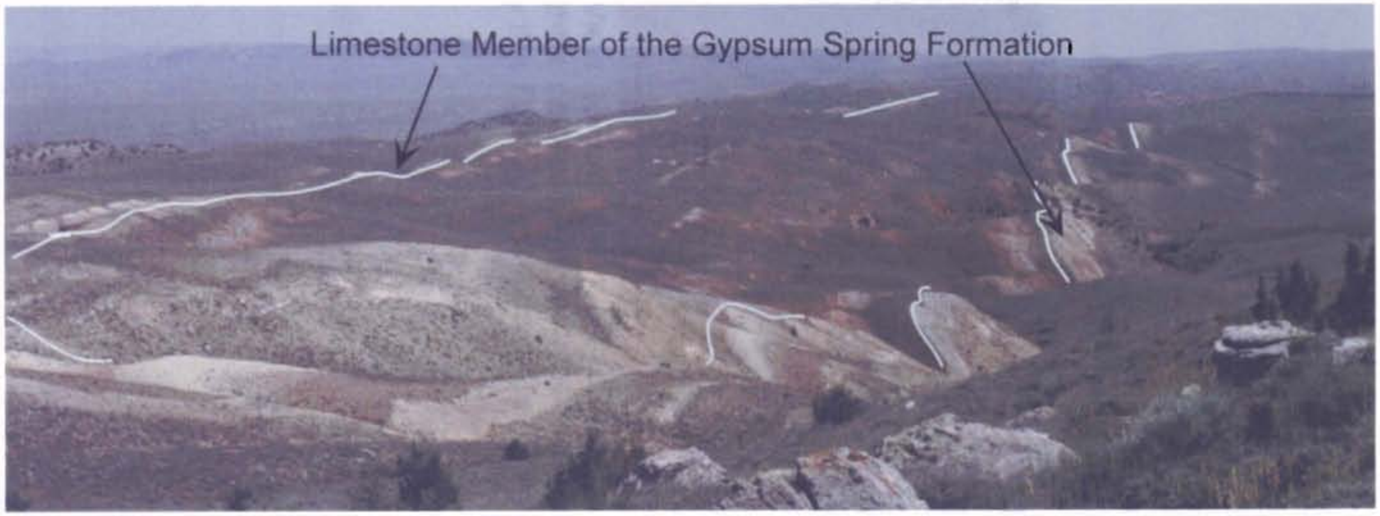

Figure 29. View looking east of the Wild Horse Butte Anticline. The geometry of the structure can best be seen in the lighter colored limestone units of the Gypsum Spring Formation.

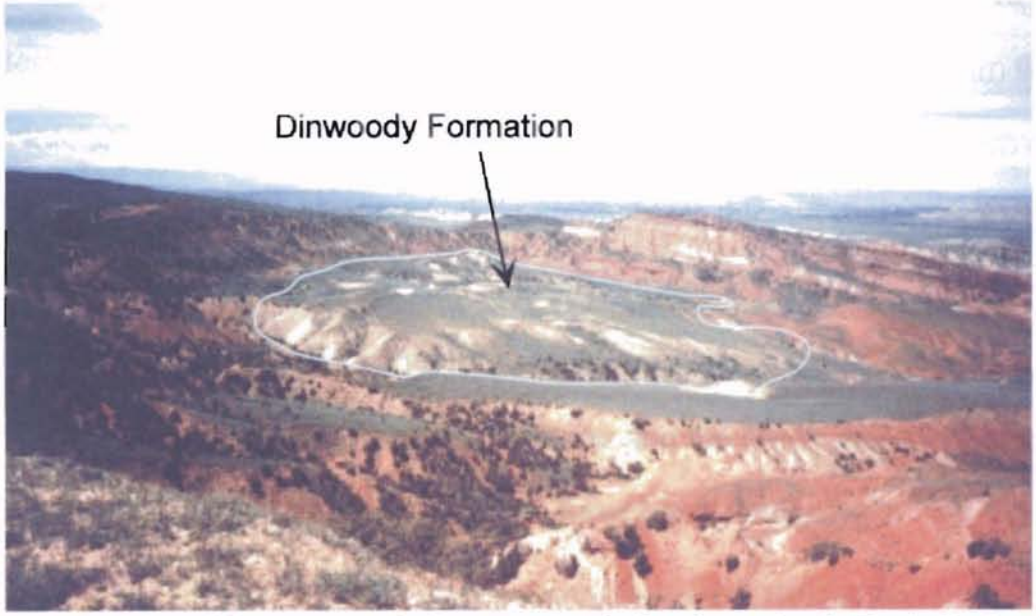

Figure 30. View toward the west of the breached Red Spring Anticline. Lighter colored Dinwoody beds are visible in the center, surrounded by the Triassic red beds of the Chugwater Group.

Shlemon (1959), is that no significant faults are visible on the surface in the sharply folded rocks of the synclines, regardless of the competency of the rock type.

Mapping along the southern limb of the anticline was difficult due to the weathered nature of the outcrop, possibly due to abundant fractures which made contacts difficult to find. Most of the contacts mapped along the southern limb of the structure were indistinct; some were inferred. The stratigraphic section on the southern limb of the Red Spring Anticline probably is thinner, as Paylor et al. (1989) discovered on the south limb of the Thermopolis Anticline. This inference is based on the fact that the same formations were folded in both anticlines, with no significant change in lithology between one and the other; moreover, forces that generated the two structures seem to have been similar.

Red Spring Fault

The only major fault mapped in the area is the previously mentioned Red Spring Fault (Figures 31 and 32). This fault is exposed best in the east wall of Red Hole, where gypsum beds in the Gypsum Spring Formation are juxtaposed with beds in the lower part of the Sundance Formation. Displacement of bedding indicates that this is a normal fault. The fault plane dips about 50° to the south (Shlemon, 1959). The offset along the fault is inconsistent due to the relationship of the fault plane to the changing attitude of the bedding planes. The fault extends northeastward from the Red Spring Anticline. This fault or another with similar trend offsets the Mowry and Thermopolis Formations near the northeast

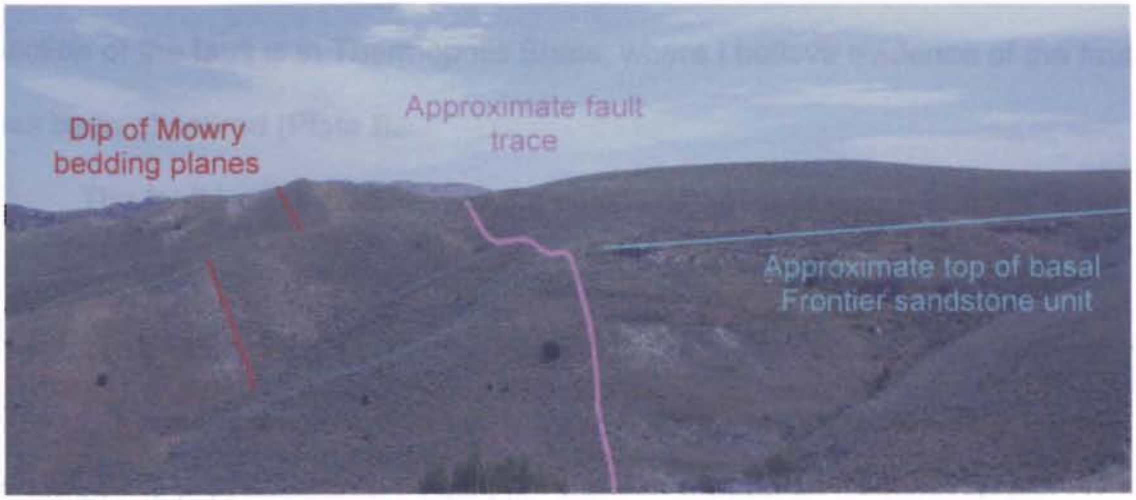

Figure 31. Truncation of the basal sandstone unit of the Frontier Formation by the Red Spring Fault near its westernmost surficial expression. This outcrop is located south of the East Warm Springs Oil Field.

Figure 32. View looking east of the Red Spring Fault as it is expressed in Red Hole. Here the fault is seen to juxtapose the Sundance Formation against the gypsum units of the Gypsum Spring Formation.

boundary of the study area. I have mapped this as a single fault and inferred its location across the area where it cannot be seen on the surface. The inferred section of the fault is in Thermopolis Shale, where I believe evidence of the fault has been obscured (Plate I).

The fault leaves Red Hole to the southwest, east of Warm Springs Road, and continues to the west along the southern limb of the Thermopolis Anticline. In this area rocks of the Sundance Formation are in fault-contact with rocks of the Cloverly Formation. A short distance southwest of Red Hole, The Cretaceous Thermopolis is in fault–contact with the Frontier Formation. The westernmost evidence of faulting is in section 1 of T42N, R94W to the east of a ranch road that crosses the fault. This is shown in Figure 30. There the fault can be seen to juxtapose basal Frontier sandstone, which dips approximately 5° to the north, with Mowry Shale, which is very steeply dipping to the south. It is possible that the fault extends to the west and enters the southern, bounding syncline of the Thermopolis Anticline. Relative motion along the Red Spring Fault is the same as what would be expected to be seen in the subsurface faults in the hinge of the syncline, based on the interpretation of Paylor et al. (1989). This would lend more weight to the proposition that the hinge of this syncline is faulted. An alternate interpretation is that the fault is compensated for and dies out in the thick section of Cretaceous shales to the west of the last western exposure.

CHAPTER IV

GEOLOGIC MAP AND MEASURED SECTIONS

Geologic Map

The geologic map that is included as Plate I was compiled throughout the course of the fieldwork in conjunction with other activities. As previously stated, geologic information was recorded on mylar sheets, combined with the 9 inch x 9 inch black and white air photographs. Due to time constraints placed on the fieldwork, all of the geologic contacts on the map were not directly observed and recorded in the field. In areas that were not accessible for various reasons, the locations of geologic contacts were interpreted by stereographic analysis of the aerial photography, and by analysis of geologic maps done by previous workers that cover portions of the area. Figures 33 to 36 illustrate the formation contacts as they are visible on the black and white aerial photography. The use of solid lines as formation contacts on the map does not convey the degree of certainty for the placement of the contacts. Only in the most unsure instances of contact placement are dashed lines used to represent the location interpreted as being most likely to be the contact. Dashed lines are used to show approximate locations of formation contacts mostly on the more distorted south limbs of the anticlines. Formations of the Chugwater Group were especially difficult to trace in areas of high distortion and compaction due to similar lithologies and colors.

The Red Spring Fault is also represented through most of the area by a solid line which again does not express the degree of certainty of the placement

Figure 33. Reproduction of B&W aerial photo. The red line shows the mapped contact between the Thermopolis and Mowry Formations. The Green line highlights the mapped contact between the Mowry and the Frontier Formations.

Figure 34. Reproduction of B&W aerial photo. The red line indicates the mapped contact between the Morrison and Cloverly Formations. The Green line highlights the mapped contact between the Cloverly and the Sykes Mountain Formations.

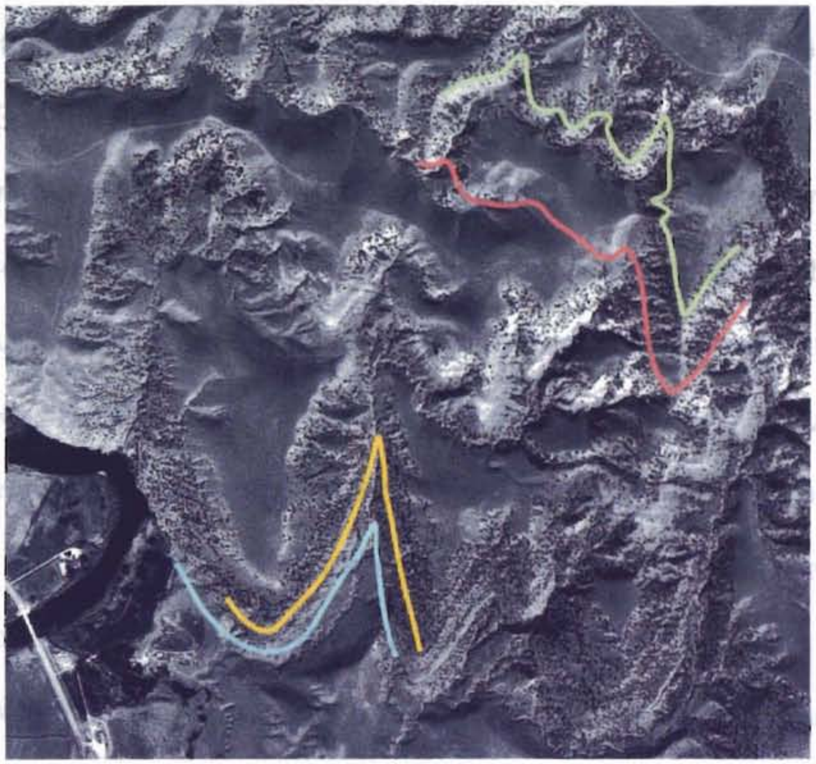

Figure 35. Reproduction of B&W aerial photo. The pink line represents the mapped contact between the *Sundance* and the Gypsum Spring Formations. The green line shows the mapped contact between the Sundance and the Morrison. The yellow line represents the mapped contact between the Crow Mountain and the Popo Agie. The blue line indicates the mapped contact between the Red Peak and Crow Mountain.

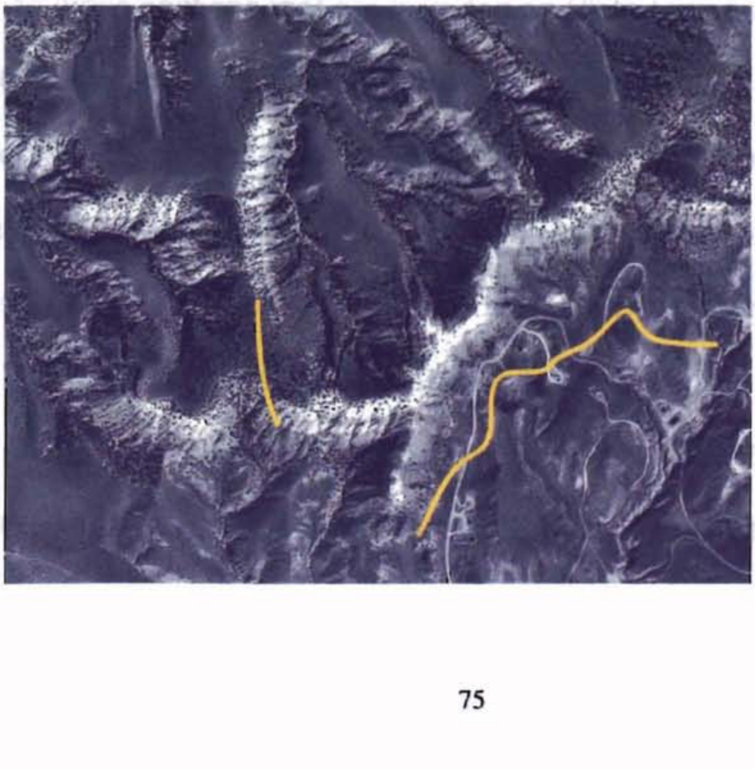

Figure 36. Reproduction of a B&W aerial photo. The Yellow lines represents the mapped contact between the Gypsum Spring and the Popo Agie.

of this fault on the map. Dashed lines are used to represent the fault in areas where fault evidence was not visible on the surface, but through which the fault is believed to continue. Alternate interpretations exist regarding the continuation of the Red Springs Fault after it exits the Red Hole.

Strike and dip measurements recorded on the map were made in the field on selected outcrops. An attempt was made to show structural trend on each major structure, thus strike and dip measurements are concentrated on areas of rapid strike and dip change. These measurements were taken using a Brunton Pocket Transit by methods of direct outcrop contact, and cross outcrop leveling. Areas of the map with low concentrations of strike and dip measurements are typically areas where access difficulty arose. These same areas are typically of rather uniform strike and dip. Thus, it is the writer's belief that no aspect of the map was compromised by not having strike and dip data in these areas.

Cross Sections

The cross sections that are included on Plate I were constructed based on information contained on the 7.5 minute topographic base maps, strike and dip measurements, geologic data that was transferred to the map, and topographic data published on the map. The thickness of the Phosphoria Formation was measured on an electric well log recorded a few miles northeast of the study area. The true thickness of the Pennsylvanian Tensleep Sandstone is not known, and is not represented on the cross sections. The base of the Tensleep was not present on available electric well logs. Lines of cross section were chosen based on the location and orientation of major structural features. Cross section A-A', which runs south to north in the western part of the study area, shows the structural interpretation, based on surface geology of the Thermopolis and Lucerne Anticlines. Cross section B-B', running south to north in the eastern part of the study area, transects the Red Spring Fault and shows the structural interpretation of the Red Spring Anticline based on the surface geology (Plate I). Both cross sections are displayed with no vertical exaggeration. The two cross sections also include a topographic profile showing outcrop surface expression of the various formations along the lines of cross section.

Measured Stratigraphic Sections

A total of six measured sections are presented. These sections are included as plates II-VII in the pocket at the back of the thesis.

Section 1

Measured Section 1 (Plate II) was measured in the west half of section 28, Township 43 north, Range 93 west. It covers the formations from the top of the Phosphoria to the base of the Gypsum Spring. This interval includes the Dinwoody, Red Peak, Crow Mountain, and Popo Agie Formations. Good outcrop of these formations was found and measured on the north limb of the Red Spring Anticline, starting near the exposed core of the structure. While measuring this section, a rock slab was found which contained several sets of vertebrate tracks. They have not been specifically identified, but are believed to be the tracks of a

Triassic amphibian species, due to the four toe impressions. The track slab was not found in place but had obviously moved several feet down slope. Hence, the exact interval of the track way was not located and no other tracks were found. The unit of origin was determined in the field, so that future exploration for similar tracks may be conducted. The unit in which the track way occurs is Unit 16 of the Red Peak. It is marked on Plate II.

Section 2

Measured Section 2 (Plate III) was recorded along the southern margin of the study area from the center of section 18 to the southwest quarter of section 7, Township 42 north, Range 94 west. Covered by this measured section are the upper Popo Agie, Gypsum Spring, Sundance, and Morrison Formations. The section was measured in two parts. The upper part, from the top of the Gypsum Spring Formation to the base of the Cloverly Formation, was measured first in order to incorporate the Sundance and Morrison. The Gypsum Spring and upper Popo Agie were added later in order to complete the Jurassic column. The section was measured on the south slope of the hill north of Buffalo Creek Road and above the cliffs of the Chugwater Group (Plate I).

Section 3

Measured Section 3 (Plate V) was measured from the northeast quarter of section 7 to the northeast quarter of section 6, Township 42 north, Range 94 west. This section includes the Cloverly and Sykes Mountain Formations. The outcrop measured invloved good exposure in the hillside to the north of Carter Ranch Road. The basal Cloverly unit here displays greater than usual thickening due to the presence of a 60 foot thick chert-conglomerate interval that incises up to 30 feet into the underlying Morrison Formation.

The coarsening upward sequences of the Sykes Mountain are not as well displayed in this area as they are in the area of Measured Section 4. This made the contact with the Thermopolis Formation more difficult to locate.

Section 4

Measured Section 4 (Plate V) was measured from the northeast quarter of section 20 to the southwest quarter of section 16, of Township 43 north, Range 93 west. Like Section 1, this column was also measured in the hogbacks on the north flank of the Red Spring Anticline. The section extends from the top of the Cloverly Formation to the base of Frontier Formation and incorporates the Sykes Mountain, Thermopolis, and Mowry Formations. No significant evidence of a disconformity surface, such as inclusions of the Cloverly in the Sykes Mountain or irregularity of the contact, was observed at the contact between the Cloverly and the Sykes Mountain. This contact has been reported by previous authors to be an unconformity. The top end of the section was placed at the Clayspur Bentonite. This same marker is used by petroleum geologists for the formation boundary between the Mowry and Frontier Formations due to its distinctive characteristics on mechanical wireline logs. At a few locations in this area the Clayspur is mined.

Section 5

Measured Section 5 (Plate IV) was measured in the northeast quarter of section 7, Township 42 north, Range 94 west. This section was described on the hill to the south of Carter Ranch Road directly downdip from the Warm Springs Ranch Dig Site. The section includes the interval from the top of the Sundance Formation to the top of the Morrison Formation. Vertebrate bone material was discovered while measuring this section. The sandstone body that contains the BB dig site was also found to continue into this area.

Section 6

Measured Section 6 (Plate VII) was measured in the center of section 8, Township 42 north, Range 94 west. This section covers the interval from the top of the Sundance Formation to the base of the Cloverly Formation. The formation of interest in this column is the Morrison Formation. The Morrison outcrop where this section was recorded occurs in the valley of Warm Springs Creek, past the eastern limit of Carter Ranch Road. The outcrop here is dominated by Morrison unit 5, which forms a 65 foot completely vertical cliff in the middle of the outcrop. The thickness of this unit was measured using an internal scale on a photograph.

CHAPTER V

CONCLUSIONS

Conclusions

1) The variability of the basal facies in the Jurassic Sundance Formation is due in large part to the presence of the Black Mountain High.

2) The lower Morrison Formation was deposited in a coastal plain setting, following the retreat of the Sundance Sea. Environments represented in this interval include fluvial channels, flood plains, and dunefields. The middle Morrison Formation was deposited in well developed meandering streams that blanketed the area. The upper Morrison Formation is the result of deposition in lacustrine environments that formed on a broad, flat alluvial plain. Interbedded mudstones and nodular carbonates of the upper Morrison Formation may indicate a seasonally variable climate during Morrison time. Bedded micritic limestone may represent lacustrine accumulation. Nodular discontinuous limestone lenses indicate caliche developed in soil horizons.

3) Overbank deposits originating from the Morrison meandering stream in sec. 8 of T42N, R94W, strongly influenced the taphonomy of the WDC dig sites.

4) The most fossil-productive intervals of the Morrison at the WDC dig sties are in the upper nodular carbonate and mudstone interval. This interval accumulated in floodplain and lacustrine environments.

5) Plant life was abundant in this area during Morrison time, as shown by the development of coal deposits, and the abundance of coalified plant material included in some of the sandstones and mudstones.

6) For the duration of deposition of the Red Peak Formation (Triassic) the study area was part of a broad, shallow marine shelf or tidal flat, highly subject to storm and tidal processes.

7) The Gypsum Spring Sea was in a partially silled basin with fluctuating degrees of salinity, ranging from brackish to hypersaturated water. This is evidenced by interbedded gypsum and mudstone in the lower part of the formation, and by the infrequent occurrence of fossil material in the Limestone Member.

8) Parts of the Cretaceous Cloverly Formation were deposited in terrestrial environments and show evidence of having supported vertebrate life. The basal sandstone and conglomerate accumulated in braided stream facies of an alluvial fan complex. Overlying red mudstones were components of a meandering stream floodplain. This interval shows promise of containing vertebrate fossil material that has yet to be found in the Warm Springs Ranch area.

Areas For Further Study

This thesis has been presented on a relatively large scale in order to examine the geology of the Warm Springs Ranch. This was the necessary first step of a project that is just a part of a much larger scientific endeavor. The close interplay of between Geology and Paleontology make these two sciences dependent of the performance of each other. It is for this reason that the Wyoming Dinosaur Center has interest in the geology of the area in which they operate. It is the hope of the writer that this work lays the foundation for further detailed geologic studies in the Warm Springs Ranch area. Based on the stated goals of this research, areas where further work may be conducted that would most likely be of interest to the WDC have been identified and will be summarized here.

There is possibility of further understanding of paleoclimate during Morrison time by detailed stratigraphic study of the Morrison interval. Other workers have proposed that the Morrison displays characteristics of having a seasonally variable climate. Valuable information could be lent to this debate based on the variability within individual depositional environments in the Morrison Formation. The Warm Springs Ranch and adjacent areas would be an ideal location to study such environments due to the varied assortment of depositional facies within the Morrison across the relatively small area of the ranch. In particular, very detailed measured sections should be carried out that record the coal unit of the Morrison which occurs approximately in the S½, sec. 25, T43N, R94W.

Another interesting feature of the Morrison in the ranch area is the development of the "eolianite" unit. This thick sand body, most likely eolian in origin, terminates laterally and is definitely more prominent in the northern part of the study area where it, in places, dominates the Morrison section. It has been suggested that this sandstone unit is a preserved dune field that developed at the shoreline of the retreating Sundance Sea. It would be possible to develop, from section measured in outcrop, an isopach map and a related paleogeographic map to show the geometry of this sand body and more definitely interpret its origin. Rock thin-section analysis would lend greatly to the conclusions of such a project.

Using a series of surface measured sections, a paleoenvironment or paleogeographic map may be constructed of the Morrison at various intervals showing the interplay and development of contiguous depositional environments within the formation.

A detailed study of the BB sandstone across the ranch would aid in defining a specific depositional model for the unit.

Identification of the lateral extent of the upper calcareous mudstone units/nodular carbonate lacustrine faces, could identify areas in which fossil exploration should be concentrated.

A stratigraphic study of the Cloverly, in particular the basal conglomeratic unit, might also be considered. This unit displays properties in some areas of being an incised valley fill rather than part of a braided stream system.

Detailed identification of depositional environments and mapping of the "lower" Sundance could produce clues to the location of new sites for verterbrate fossils and vertebrate trackways. As stated by Schmude (2000), the area of the Black Mountain High may produce vertebrate trace fossils in the shallow marine environments similar to those found at the Red Gulch Track Site near Shell, Wyoming.

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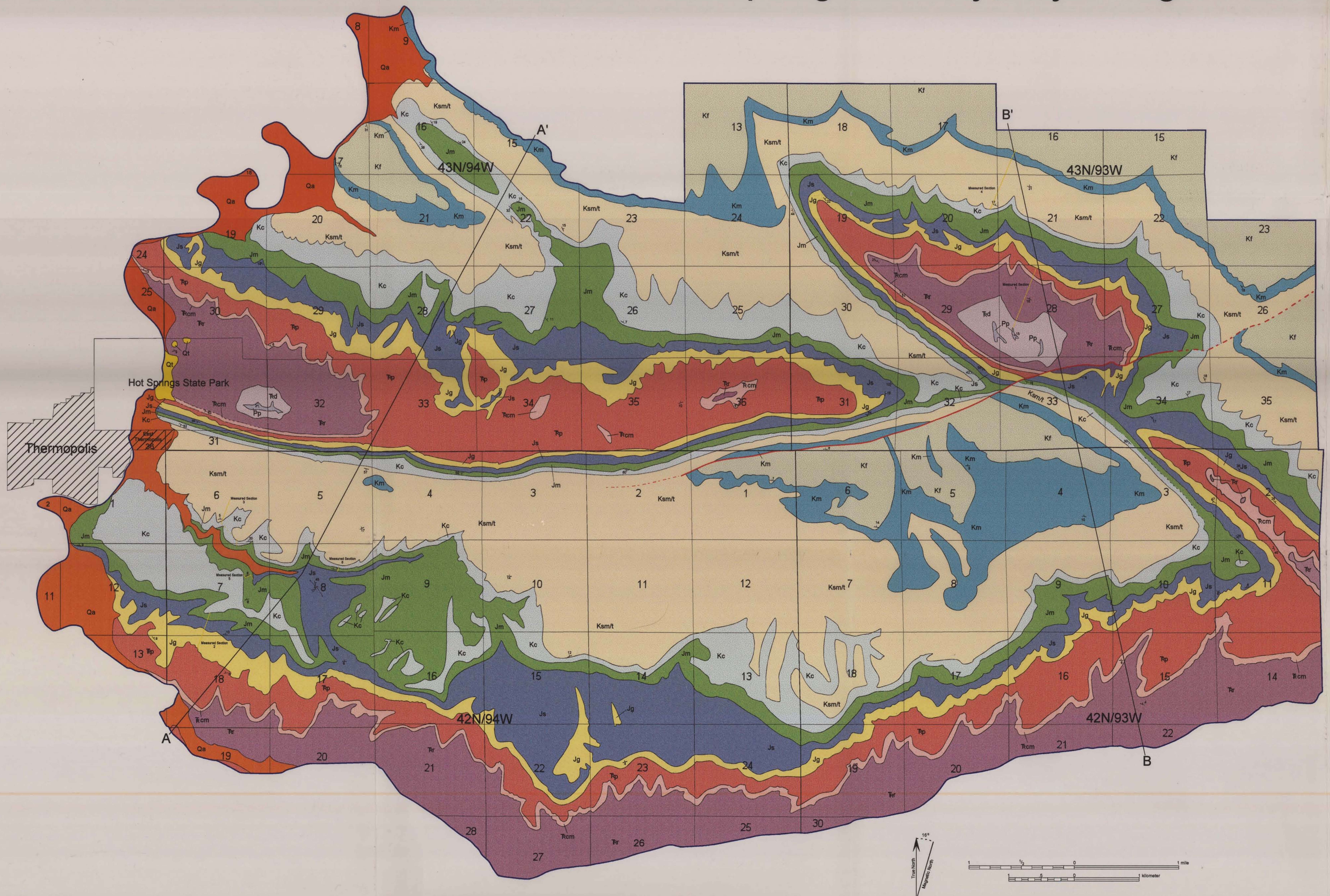
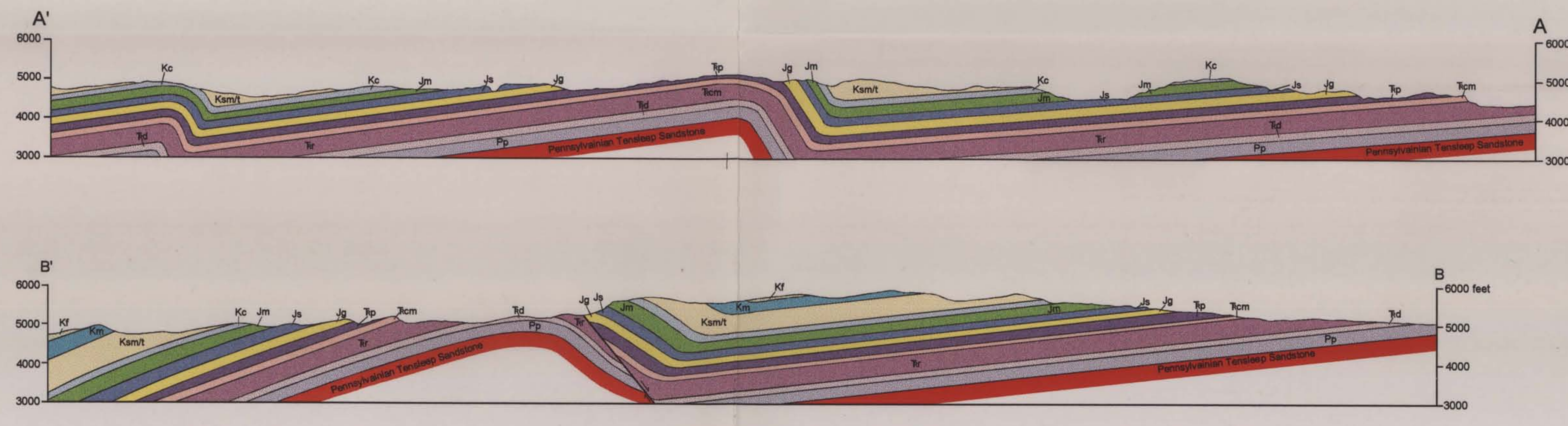
PLATES

1, 2, 3, 4, 5, 6, and 7

Plate I

Geologic Map of the Warm Springs Ranch Area, Hot Springs County, Wyoming





Key

Quaternary

Qa
Quaternary Alluvium
Flood plain alluvium

Qt
Quaternary Travertine
Travertine deposits from hot springs.

Cretaceous

Upper Cretaceous

Kf
Frontier Fromation
Gray silty shale coarsening upward into light gray to light brown sandstone.

Lower Cretaceous

Km
Mowry Shale
Gray marine shale and siltstone.

Ksm/t
Sykes Mountain and Thermopolis Shale Formations (Undifferentiated)
Series of coarsening upward sequences in lower 100', sandstones and shales. Dark gray marine shale, and single sandstone unit.

Kc
Cloverly Formation
Sandstone, conglomerate, and mudstone. Mudstones are dark red to medium reddish gray, sandstones are light brown to dark gray.

Jurassic

Upper Jurassic

Jm
Morrison Formation
Claystone, mudstone, and sandstone. Varicolored, red, green, and light gray.

Js
Sundance Formation
Limestone and clay shale in "Lower" Sundance. Shale capped by glauconitic sandstone in "Upper" Sundance.

Middle Jurassic

Jg
Gypsum Spring Formation
Massive gypsum in lower part, red mudstone in middle, limestone in upper part.

Triassic

Upper Triassic

TRp
Popo Agie Formation
Brick red, blocky mudstone and siltstone.

TRcm
Crow Mountain Formation
Brick red, sandstone and siltstone, cliff forming. This unit includes the Alcova Limestone

Lower Triassic

TRr
Red Peak Formation
Brick red, mudstone, and siltstone. Gypsiferous in lower part.

TRd
Dinwoody Formation
Massive laminated gypsum and gypsiferous mudstone.

Permian

Pp
Phosphoria Formation
Dolomitic limestone, light gray with petroliferous odor,

Legend

Formation Contact

Thesis area boundary

Red Spring Fault

Red Spring Fault where location is unceartain

Formation Contact where location is unceartain

Line of Measured Section

14 Strike and Dip measurement

Chris J. Carson

M.S. July 2000

Structrual and Stratigraphic Framework of the Warm Springs Ranch Area, Hot Springs County, Wyoming

Plate II

Section 1

Stratigraphic Section of the Dinwoody, Red Peak, Crow Mountain, & Popo Agie Formations

	Base	*Top*
UTM:	12T 0739384 4838624	12T 0739504 4839384
Lat:	N43d 39m 51s	N43d 40m 16s
Lon:	W108d 01m 50s	W108d 01m 43s

PLS: W 1/2, sec. 28 T43N, R93W

Unit Description

Massive, powdery, gypsum. White, few gray stringers.

Nonfissle mudstone, noncalcareous. Dark brick red

Very fine sandy, siltstone, calcareous, abundant burrowing with no dominant direction. Nonfissle mudstone in bottom 1.9', grades upward into siltstone portion of unit. Medium brick red, leached to medium gray in upper 1.5'.

Very fine sandy, siltstone, calcareous, abundant burrowing with no dominant direction. Medium brick red.

Nonfissle mudstone, weathers blocky, calcareous. Contains very hard calcitic, nodular structures (glaebules?), sharp irregular lower contact, gradational upper contact. Dark brick red.

Very fine sandy, siltstone, calcareous, abundant burrowing with no dominant direction. Medium brick red.

Very fine sandy, siltstone, calcareous, weathers blocky. Dark brick red.

Silty, very fine sandstone, calcite cemented, quartz-arenite.

Nonfissle mudstone, calcareous, irregular upper and lower contacts. Dark brick red, tannish-gray in lower few feet.

Silty, very fine sandstone, calcite-cemented, quartz-arenite. Well indurated, massive bedding. Very light gray.

Very fine sandstone, calcite-cemented, quartz-arenite. Indistinct cross-bedding, irregular bedding surfaces. Medium brick red.
Silty interbeds are present increasing in frequency upward through the unit.

Very fine sandstone, submature, calcite-cement, quartz-arenite. Few thin more erodable beds in middle of unit. Some liesegang banding and few indistinct cross beds. Grayish-tan.

The lower few inches of this unit contains limestone granules and pebbles, apparently eroded from the Alcova.

Micrite, algal laminated, some inclusion of sand and silt grains. Sharply erosional upper contact. Medium gray.

Silty, very fine sandstone, hematite-cemented, quartz-arenite to sub-arkose. Abundant hummocky cross bedding. Medium to dark brick red.

Silty, very fine sandstone beds interbedded with mud shale. Sandstone beds display hummocky cross bedding and ripple marks on bedding planes. A few four toed vertebrate tracks were found on some bedding planes.

Silty, very fine sandstone, abundant small to medium scale hummocky cross bedding, convolute bedding occurs in upper 1' of top sandstone bed. Dark brick red. Middle 5' is mud shale with siltstone interbeds. Medium brick red. Rocks of this and adjacent units are leached and oil stained in some areas.

Individual bed of silty, very fine sandstone, calcite-cemented, quartz-arenite. Small scale hummocky cross bedding.
Medium gray. 5.8' thick

Shally, siltstone, calcite-cemented, dark brick red.

Laminated, micrite with shale interbeds. Limestone beds are 1"-2", include algal material, light dull gray. Shale intervals are 2"-3" and similar color. Unit forms a very visible light colored band on slope

Silty, very fine sandstone, calcite-cemented, quartz-arenite, possibly sub-arkose. Sub-horizontal gypsum veins. Dark brick red.

Sandstones appear to fine upward into siltstones.

Coarse siltstone, calcite-cemented, fibrous gypsum veins. Medium brick red. Indistinct ripple marks on bedding surfaces.

Unit is mostly covered. It is inferred to be similar to unit 11, directly above.

Silty, very fine sandstone, calcite-cemented, quartz-arenite. Mudstone interbeds in upper 8'. Sandstone beds display ripple lamination. Unit outcrops poorly due to recessive weathering. Dull greenish-gray and medium brick red.

Very fine sandy, coarse siltstone, and thin intervals of mudstone. Siltstones are plane bedded and trough cross bedded. Siltstones are dull brick red and mudstones are whitish-gray.

Calcareous mudstone. Contains three intervals of coarse siltstone flags with small scale trough cross bedding. Dull yellowish-brown.

Silty, very fine sandstone, calcite-cemented, quartz-arenite. Plane bedding with some trough cross lamination in lower portion of unit. Large scale low angle trough cross bedding occurs in the middle portion of the unit.

Mudstone, interbedded flags of rippled, cross laminated, calcite-cemented, coarse siltstone. Dull yellowish brown. Becomes very silty in upper portion.

Very fine sandy, siltstone, silica and calcite cement. Blocky weathering. Abundant gypsum as wavy fibrous crusts in lower 9'. Thin interbedded mudstones. Siltstones show hummocky cross bedding, with oscillation ripples. Light brick red.

Silty, very fine sandstone, calcite-cemented, possible subarkose. Plane bedding and trough cross bedding.

Nonfissle mudstone, slightly calcareous. Dark brown.

Silty, very fine sandstone, calcite-cemented, mature, quartz-arenite. Light gray.

Mud shale. Few thin (1/4") gypsum veinlets. Brick red.

Slightly silty, very fine sandstone, silica and gypsum cemented. Blocky weathering, abundant gypsum as wavy fibrous crusts in lower 9'. Small-scale trough cross bedding near top and bottom of unit. Light brick red.

Mud-shale, slightly calcareous. Fibrous gypsum crusts near lower contact. Brick red.

Gypsiferous mud-shale, discontinuous wavy gypsum crusts, ovate blebs of weathered pyrite. Light whitish-gray to light gray

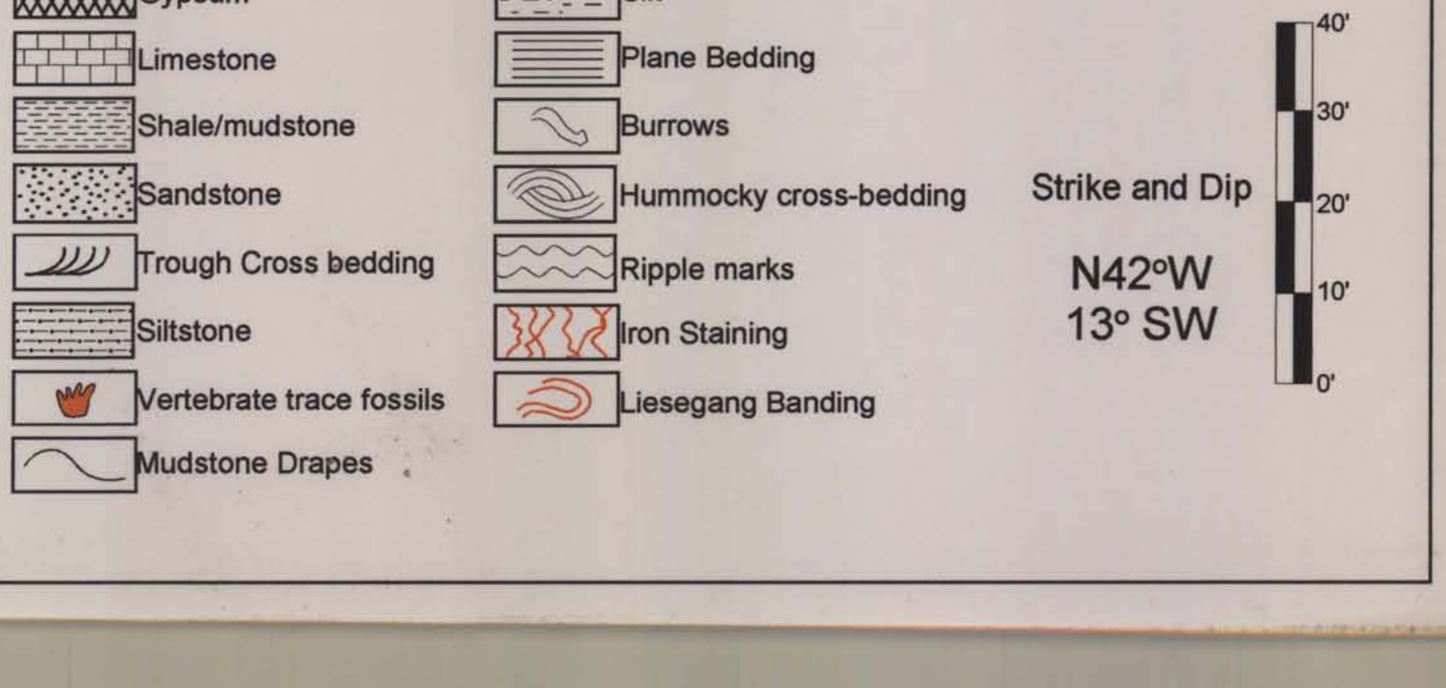
Argillaceous, laminated, fibrous to powdery gypsum. White to dull gray.

Gypsiferous mudstone, discontinuous fibrous gypsum crusts up to 1/4" thick, dull grayish white.

Non fibrous gypsum in lower 3'. Becomes gypsiferous mudstone in upper 2.4'. White to dull gray.

Dolomitic dismicrite, oblong inclusions of spar, flaggy bedded. Dull gray. Hydrocarbon odor.

Legend



Strike and Dip

N42°W
13° SW

Plate III

Section 2

Stratigraphic Section of the Gypsum Spring, Sundance, and Morrison Formations

	Base	*Top*
UTM:	12T 0727102 4832072	12T 0727526 4833072
Lat:	N43d 37m 33s	N43d 37m 04s
Lon:	W108d 11m 10s	W108d 10m 47s

PLS: Middle, N 1/2, sec. 18; SE1/4, sec. 7 T42N, R94W

Unit Description

Slightly silty, medium to coarse sandstone, immature, silica-cemented, chert-arneite.
Large scale trough cross-beds are abundant, and filled with granule to pebble chert conglomerate.

Coarse sandstone, submature, calcite-cemented, quartz-arenite. Medium to large scale trough cross-beds. Some cross beds contain mud drapes and small conglomeratic lenses.

*Unit 8 is incorporated from section measured in nearby quarry

Dull greenish gray.

Slightly fine sandy, blocky, mudstone. Interbedded lenticular micrite and dismicrite limestones

Individual bed of very fine sandstone, submature, silica cemented, Quartz-arenite.

Micrite limestone beds, containing recrystallized microfossils of unknown type. Nonfissle mud shale separates the two limestone beds. Dull gray limestones and dull greenish gray mudstone.

Level of Bone Bed Site

Unit is largely covered. Few exposures of nonfissle mud shale.

Fine sandstone, mature, calcite-cemented, quartz-arenite. Friable, large scale trough cross-bedded. Grayish white.

Mostly cover, assumed to be more nonfissle, mud shale.

Silty, fine sandstone, mature, calcite cemented, friable, quartz-arenite. Darker striations on rock surface indicate medium scale trough cross-bedding. Unit displays a sharply erosional base. The top is largely covered by slope talus. Dull yellow tan.

Nonfissle, mud shale.

4' thick interval of fine sandstone, mature calcite-cemented, quartz-arenite. Planar bedding, and medium scale trough cross-bedding. Grayish white.

Nonfissile, mud shale.

Fine sandstone, mature, silica-cemented, quartz-arenite. No glauconite. Dull yellow tan.

Platy, friable, fine sandstone, sub-mature calcite cemented, glauconitic, quartz-arenite. Weakly cemented, highly friable fine sandstone interbeds. Light grayish green

Thinly bedded, glauconitic, fine sandstone, sub-mature calcite-cemented, quartz-arenite. Small-scale trough cross-beds and some hummocky cross bedding. Light grayish green

Thick bedded-massive, small-scale bimodal trough cross-bedding. Fine-very fine sandstone, calcite-cemented, mature, glauconitic quartz-arenite.

Base of unit displays load casts.

Interbedded silty, slightly sandy, shale showing delicate lamination and thin plates of sandstone 1/4"-2" thick. Sandstone plates are burrowed and haveoscillation ripples.Silty, very fine sandstone, calcite-cemented slightly glauconitic quartz-arenite. Molluscan shell hash occurs on some bedding planes as do trace fossils Shell hash is developed into bivalve coquina flags at some intervals. Greenish yellow.

Shales become more resistant and form steeper slope. Gryphaeids and Belemnites are no longer present.

Much of slope is largely covered

Slightly calcareous clay shale.
Belemnites are found on slope throughout unit.
Greenish-brown to yellow.

Slightly silty, fissle, clay shale. Greenish yellow.

Flaggy bedded fine-very fine sandstone, calcite-cemented, slightly glauconitic, quartz-arenite.
Possible hummocky cross bedding, symmetrical ripples and interference ripples.
Occurs in lower 20' of unit 4

Silty very fine sandstone, calcite-cemented, quartz-arenite. Vertical burrows approx. 1/2" dia.
Symmetrical ripples on upper bedding surfaces.
Dull Yellow.

Individual bed of fine-very fine sandstone, calcite-cemented, mature quartz-arenite. Small scale trough
cross beds. Light browinsh yellow.

Calcareous clay shale. No macrofossils

Fine-very fine sandstone, calcite-cemented, mature quartz-arenite. Large scale trough cross-beds in lower 10'. Becomes silty in upper 10' with medium-scale trough cross laminations. Yellowish white.

Erosional basal contact marked by occurrence of black chert pebbles and undulating contact.

Non fissile mud shale. Brick red.

Medium bedded micrite. No fossils. Very light gray.

Calcareous clay shale.

Medium bedded micrite. Few bivalves present, found on green colored bedding planes. Medium to light gray.

Calcareous mud shale with interbedded thin plates of grayish-white micrite limestone.

Micritic, limestone. Wavy bedding, abundant algal laminations flaggy bedded. Carbonate shale interval in middle of unit. In some areas a 3" thick bed of coquina was found, composed of intact gastropod shells. Medium gray.

Mud shale. Some interbedded gypsum nodules, and veinlets. Minor amount of interbedded green siltstone Gypsum nodules and veinlets decrease upward from base to top of unit. Medium brick red.

Mudstone. Few thin gypsum nodules and veinlets. Medium brick red.

Massive powdery, white gypsum. Mudstone interbeds in lower 8'

Massive bedded gypsum. Slightly grayish white.

Mudstone with irregular stringers and blebs of green claystone.

Individual bed of very fine sandstone: immature, silica and hematite cemented, quartz-arenite. Medium brick red.

Silty, fine sandstone, immature, silica and hematite
cemented, quartz-arenite. Friable, sharp flat upper and lower contacts. Dull reddish brown

Nonfissle, mud shale. Medium reddish brown

Silty, very fine sandstone, immature, silica-cemented quartz-arenite. Massive bedded. Dull reddish-brown.

Nonfissle, mud shale. Contains blebs of green siltstone. Becomes nodular and slivery in upper 4'. Dull to medium brick red.

Legend

- ▩ Gypsum
- ▦ Limestone
- ▤ Shale/mudstone
- ▒ Sandstone
- Trough cross bedding
- Black Chert Pebbles
- Marine Fossils
- Mudstone Drapes
- Silt
- ▤ Plane Bedding
- ▒ Conglomerate
- Siltstone
- Hummocky cross-bedding
- Oscillation Ripples
- Iron Staining
- Liesegang Banding
- Burrows

Strike and Dip

N85°W
10° NE

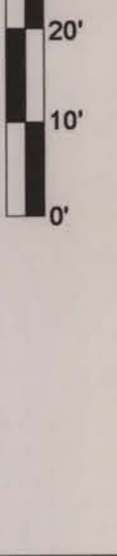


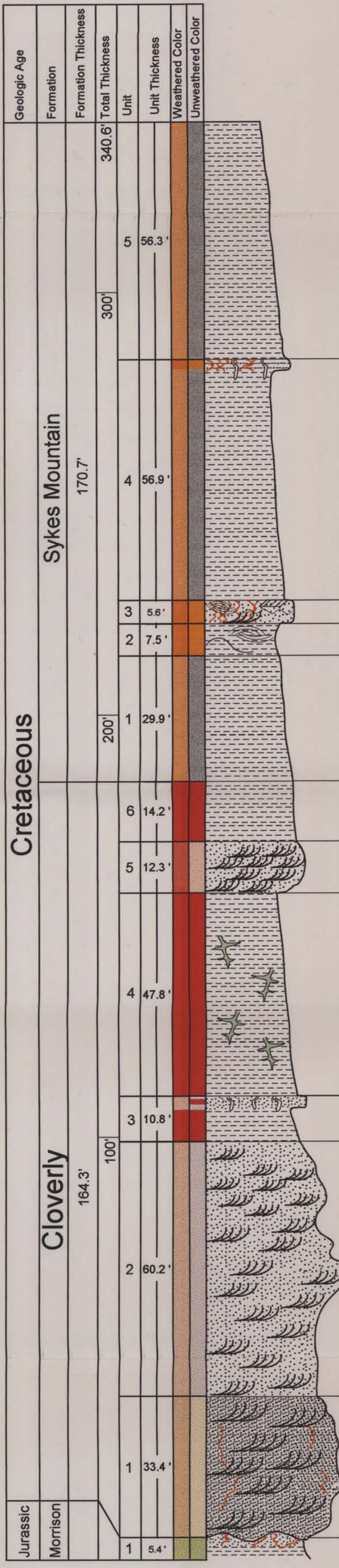
Plate IV

Section 3

Stratigraphic Section of the Cloverly & Sykes Mountain Formations

	Base	*Top*
UTM:	12T 0727336 4834364	12T 0727696 4835408
Lat:	N43d 37m 44s	N43d 38m 19s
Lon:	W108d 10m 57s	W108d 10m 39s

PLS: NE1/4, NW1/4, NE1/4, sec. 7 T42N, R94W



Unit Description

Gradational contact with Thermopolis occurs in this unit. It was not possible to exactly place the contact due to cover and the nature of the contact.
Medium to dark gray.

Upper 1.2' of this unit is ironstained, calcareous siltstone. Bioturbated by horizontal burrowing.

Fissile, noncalcareous, shale. No fossils. Silt content increases upward from none in the lower part of the unit. Medium to dark gray.

Fine sandstone, mature, silica-cemented, quartz-arenite. Heavy iron staining, hummocky cross bedding, trough cross bedding, tabular-planar cross bedding, symmetrical ripples, flaggy bedding, and Iron nodules. Tan to light tan

Siltstone and shale interbeds. Flaser bedding, hummocky cross bedding, iron nodules. Tan to light tan

Fissile, slightly silty, clay shale. Limonite stained frequently. Thin siltstone interbeds occur and increase in frequency upward. Medium gray

Nonfissile mud shale, slightly calcareous. Isolated blebs of limonite staining. One gastrolith was found on the slope. Dark brick red to maroon.

Slightly silty, fine sandstone, submature, silica-cemented quartz-arenite. Large scale trough crossbeds, small scale trough cross beds. Medium tan

Nonfissile mud shale, slightly calcareous. Few root traces, calcite glaebules found weathering out of the slope. Pieces of limestone found on slope, possibly derived from a well developed caliche. Dark red to maroon

Blocky mud shale, slightly calcareous. Unit capped by very fine sandstone, calcite-cemented, quartz-arenite. displaying burrows in upper few inches. In at least one location, this sandstone develops into a channel fill which is scoured into unit 2. Dark red to maroon.

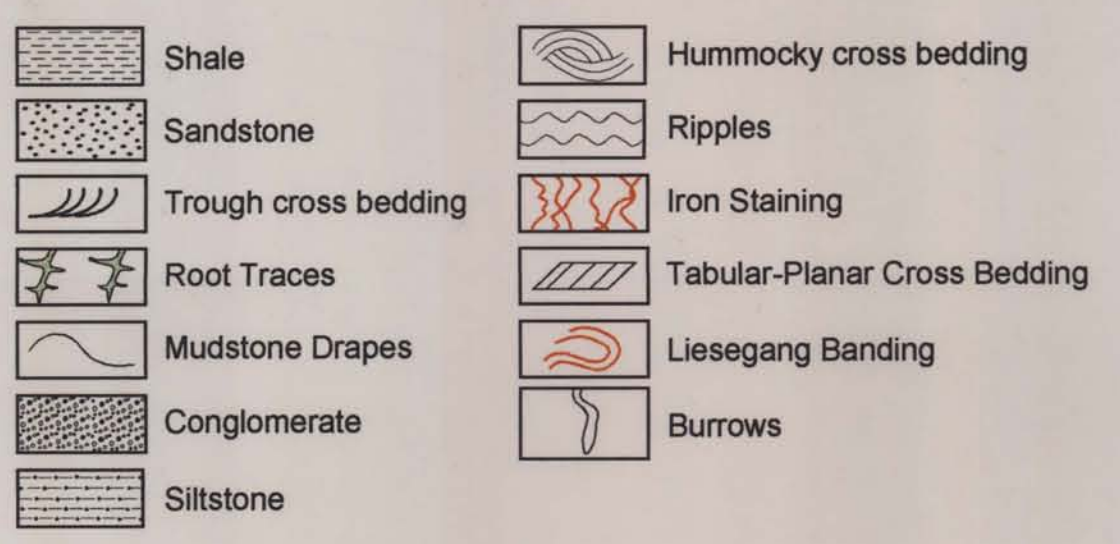
Coarse sandstone, submature, calcite-cemented, quartz-arenite. Medium to large scale trough cross beds. Few small to medium scale tabular cross beds. Few widely disbursed conglomeratic lenses. Light tannish gray.

Slightly silty, medium to coarse sandstone, immature, silica cemented, chert-arenite.
Large scale trough cross beds are abundant, and filled with granule to pebble chert conglomerate. Light grayish tan.

Erosional lower contact, few mud chips present.

Very fine sandstone, submature, quartz-arenite. Limonite staining. Blocky, silty, clay shale below. Dull greenish gray.

Legend



Strike and Dip

N87°W
05°NE

Plate V

Section 4

Stratigraphic Section of the Sykes Mountain, Thermopolis, & Mowry Formations

	Base	*Top*
UTM:	12T 0738744 4840600	12T 0739480 4841552
Lat:	N43d 39m 55s	N43d 41m 25s
Lon:	W108d 02m 16s	W108d 01m 40s

PLS: NE1/4, sec. 20; NW1/4, sec. 21; SW1/4 sec. 16
T43N, R93W.

Unit Description

Clay Spur Bentonite. Bentonitic claystone. Very light gray.

Clay shale, finely bedded, friable, no fossils. Individual well indurated siltstone bed occurs 10' from top of unit

Very fine sandy siltstone, clay drapes, iron stained

Individual siltstone bed. Very fine sandy siltstone, mud drapes, burrows, iron stained. Approx. 4" thick.

Slightly silty, clay shale, well-bedded , well-indurated, abundant fish scales. 3' interbeds of lighter colored more resistant, more silty shales with fewer fish scales. More resistant intervals are iron stained. Medium and light gray alternating bands.

Rocks become more resistant and begin to form slope in this area.

Shales above this point become more palisaded.

Transition from Thermopolis to Mowry occurs in this area. End of vegetation and start of steeper slope. Shales become more siliceous here and weathered debris of the Mowry covers the slope.

Silty, clay shale. Dark gray Detailed description is difficult due to extreme cover of this unit throughout area.

Fine sandstone, submature, silica-cemented, quartz-arenite.Irregular bedding planes, tabular-planar cross-bedding,heavily burrowed (vertical and horizontal), some plane bedding, some asymmetrical ripples. Medium tan.

Silty, clay shale. Limonite staining in fractures. Occasional thin siltstone interbeds approx. 1/4". Unit appears to coarsen upward into the Muddy Sandstone. Very dark gray.

Fissile, clay shale. Some limonite staining along fractures. No fossils, noncalcareous. Dark gray.

The gradational contact from Sykes Mountain to Thermopolis occurs in this area. Due to the nature of the contact and slope cover the contact could not be placed exactly.

Unit consists of silty, clay shale with silt content increasing upward. Unit is capped by a well indurated, burrowed, very fine sandy siltstone. Bluish gray

Unit consists of silty clay shale with silt content increasing upward. Unit is capped by a well indurated, burrowed, very fine sandy siltstone. Bluish gray.

Unit consists of silty, clay shale with silt content increasing upward. Unit is capped by a well indurated, burrowed, very fine sandy siltstone. Blueish gray.

Fissile, clay shale

Fine-medium sandstone, submature, hematite cemented, quartz-arenite. Tabular-planar cross bedding and straight crested ripples on bedding surfaces. Sharp upper and lower contacts. Medium brown

Silty, clay, nonfissle, mud shale. Limonite staining along vertical fractures, occurs most heavily near top of unit. Purplish gray

Strike and Dip

N66°W
17° NE

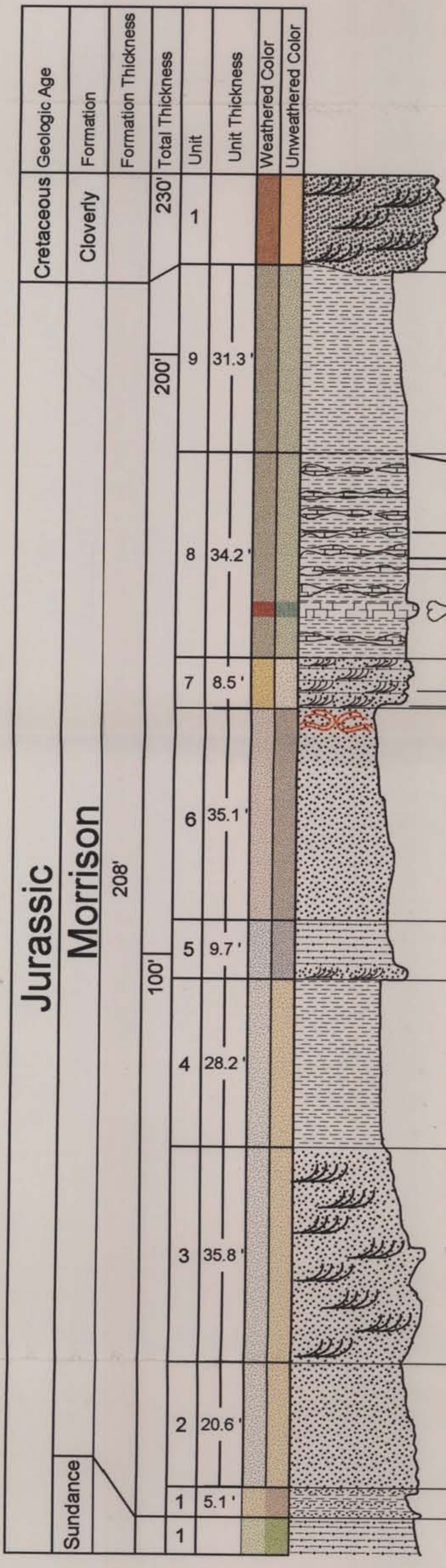
Plate VI

Section 5

Stratigraphic Section of the Morrison Formation

	Base	Top
UTM:	12T 0727648 4833768	12T 0727480 4833840
Lat:	43 37' 26"	43 37' 23"
Lon:	108 10' 43"	108 10' 37"

PLS: Center, NE1/4, sec. 7 T42N, R94W



Unit Description

Slightly silty, medium to coarse sandstone, immature, silica-cemented, chert-arenite. Large scale trough cross-beds are abundant, and filled with granule to pebble chert conglomerate. Light to medium tan

Nonfissile mudstone. Glaebules in lower few feet.

Level of AM Site

Mud shale and nodular carbonate interbeds. Some silty, very fine sandstone lenses. Abundant coalified plant material.

Level of FS Site
Level of SI Site
Level of TH Site

Carbonate cemented mudstone. Very well indurated. Vertebrate bone material found weathering out of the unit.

Level of Bone Bed Site

Fine sandstone with interbedded siltstones, submature calcite cemented, quartz-arenite. Small scale trough-cross beds, some hematite staining. Unit appears to be composed of 3-4 coarsening upward beds approx. .75' each. Light Tan

Fine sandstone, mature, calcite-cemented, quartz-arenite. Light amount of liesegang banding in upper few feet of unit, no noticeable bedding. Poor outcrop, friable surface. Medium gray

Silty, fine sandstone, mature, calcite-cemented, quartz-arenite. Small scale indistinct trough cross-beds. Friable surface forms toe in slope. Grades to siltstone in top 6'. Light gray.

Mostly covered slope. Most likely nonfissle mudstone, possibly silty.

Fine sandstone, mature, calcite-cemented, quartz-arenite. Easily erodable, outcrops in small gullies on slopes. Indistinct, medium trough cross beds. Highly friable surface. Medium tan

Unit mostly covered. Inferred to be very similar to Unit 3.

Fine to very fine sandstone, mature, calcite-cemented, quartz-arenite. Thin bedded and friable. Middle 3' has shale interbeds 1/2" thick. No Glauconite. Dull tan

Glauconitic siltstone, wavy laminated. Contains very fine sand and silt quartz grains. Light grayish green.

Legend

- ▦ Limestone
- ▤ Shale/mudstone
- ⁘ Sandstone
- ⌇ Trough Cross bedding
- ▩ Conglomerate
- ▤ Siltstone
- ⊂⊃ Vertebrate Fossil Material
- ▧ Iron Staining
- ◎ Liesegang Banding

Strike and Dip

N76°E
50° NE

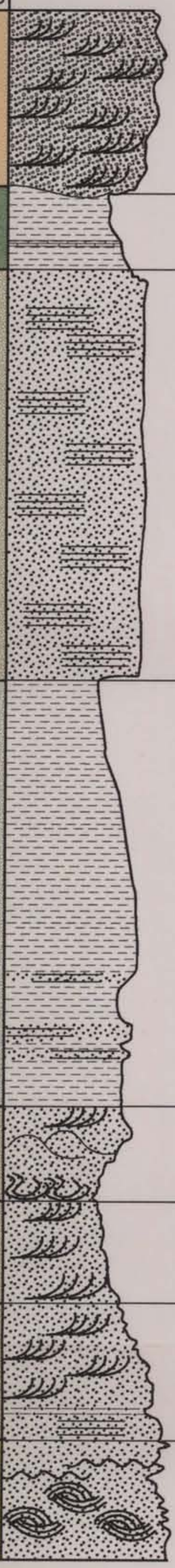
Section 6

Stratigraphic Section of the Morrison Formation

	Base	*Top*
UTM:	12T 0729048 4833948	12T 0729056 4834010
Lat:	N43d 37m 31s	N43d 37m 33s
Lon:	W108d 09m 40s	W108d 09m 39s

PLS: Middle, N1/2, sec. 8 T42N, R94W

Geologic Age	Formation	Formation Thickness	Total Thickness	Unit	Unit Thickness	Weathered Color	Unweathered Color	Unit Description
Cretaceous	Cloverly		230'	1		🟫	🟧	Slightly silty, medium to coarse sandstone, immature, silica-cemented, chert-arenite. Large scale trough cross beds are abundant, and filled with granule to pebble chert conglomerate.
Jurassic	Morrison	186'	200'	6	12.5 '	🟩	🟩	Calcareous siltstone. sharp lower contact, erosional upper contact. Thin interbed of silty very fine well indurated silty mudstone, brick hard. Dark greenish gray.
				5	60.8 '	🟫	🟩	Fine to medium sandstone, calcite-cemented, submature quartz-arenite. Plane bedded, no other sed. structures visible. Forms significant cliff. Sharp upper contact, erosional lower contact. Light grayish green.
			100'	4	63.2 '	⬜	🟩	Very fine sandy, calcareous, mud shale. Marly in some areas Erosional upper contact. Light grayish-green Interbeds of silty sandstone, submature, quartz-arenite. Plane bedded
				3	13.9 '	🟩	🟫	Silty, fine sandstone, calcite-cemented, submature, quartz-arenite. Includes mud drapes, clay layers, load structures, ripple lamination. Bedding is laminated. Medium scale wedge set trough cross beds in upper 7'. Medium greenish gray.
				2	15.3 '	⬜	🟫	Silty, very fine sandstone, calcite-cemented, submature, quartz-arenite. Large-scale trough cross bedding decreasing in size to medium in upper 4". Some limonite staining parallel to bedding planes. Sharp upper and lower contacts. Light greenish gray.
				1	20.2 '	🟫	🟫	Slightly silty, very fine sandstone, submature, calcite-cemented quartz-arenite. Thick bedded, some plane bedding in lower 3', small-scale trough cross bedding in upper 15'. Individual siltstone bed at approx. 2.5". Sharp lower contact. Slightly greenish-light gray.
	Sundance			1	18.0 '	🟩	🟩	Glauconitic, fine-medium sandstone, calcite-cemented, quartz-arenite. Small scale hummocky cross bedding, symmetrical ripples. Medium grayish green



Legend

▤ Shale/mudstone	▩ Conglomerate
⁘ Sandstone	▤ Siltstone
⌇ Trough Cross-bedding	◠ Hummocky cross-bedding
┅ Silt	∿ Ripples
≡ Plane Bedding	

Strike and Dip

N90°E
09° N

VITA

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Candidate for the Degree of

Master of Science

Thesis: THE STRUCTRUAL AND STRATIGRAPHIC FRAMEWORK OF THE WARM SPRINGS RANCH AREA, HOT SPRINGS COUNTY, WYOMING

Major Field: Geology

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