



Stratigraphy and depositional environment of the Upper Mississippian Big Snowy Group in the Bridger Range, southwest Montana
by Gary Eich Guthrie

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Science
Montana State University
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Abstract:

The Big Snowy Group is restricted to a trough which extends from southwest Montana into the Williston basin. Thickness variation of the group on the southern margin of the trough reflects movement of structural elements along an ancient structural weakness located in the central Bridger Range. Field and petrographic data are integrated to determine the depositional environment and stratigraphy of the group and to document the tectonic influence on sedimentation along this zone.

The group is divided into the Kibbey Formation, with two informal members, and the Lombard facies of the Heath Formation. The lower Kibbey is supratidal algal laminated dolostone with dessication features and evaporite solution breccias were deposited at the leading edge of the transgressing Big Snowy sea. Siliciclastic intertidal channels on the sabkha are restricted to the central range where subsidence was greatest. The upper Kibbey and Lombard facies provide further evidence of a trough in the central Bridgers. The upper Kibbey is a regressive shoreface deposit composed of fine grained sandstone at the northern and southern ends of the range. Mudstone and siltstone dominate in the center of the range where deeper water and lower energy conditions prevailed. Ultimately, the Kibbey shoreface transgressed out of the area and the Lombard facies was deposited in a partially restricted shelf lagoon. Shale and lime mudstone accumulated in the center of the range, to the north and south bioclastic wackestones, packstones, and grainstones were deposited in shoaling, higher energy conditions.

All three units of the group are thickest in the central Bridgers and thin north and south onto the Lombard arch and Wyoming shelf.

Deeper water lithologies occur with the thick sections indicating that the central part of the range subsided relative to the Lombard arch and Wyoming shelf during sedimentation. A small positive trend in the central range trough is a local exception to the pattern. This paleotectonic pattern also operated during pre-Amsden uplift and erosion and thinned the group on the positive elements more. Evidence of similar paleotectonic influence on sedimentation along the structural weakness in the Bridgers is also found in Proterozoic and other Paleozoic rocks.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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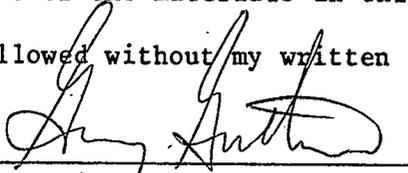
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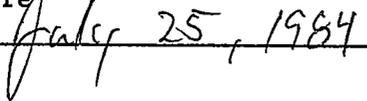
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ABSTRACT

The Big Snowy Group is restricted to a trough which extends from southwest Montana into the Williston basin. Thickness variation of the group on the southern margin of the trough reflects movement of structural elements along an ancient structural weakness located in the central Bridger Range. Field and petrographic data are integrated to determine the depositional environment and stratigraphy of the group and to document the tectonic influence on sedimentation along this zone.

The group is divided into the Kibbey Formation, with two informal members, and the Lombard facies of the Heath Formation. The lower Kibbey is supratidal algal laminated dolostone with dessication features and evaporite solution breccias were deposited at the leading edge of the transgressing Big Snowy sea. Siliciclastic intertidal channels on the sabkha are restricted to the central range where subsidence was greatest. The upper Kibbey and Lombard facies provide further evidence of a trough in the central Bridgers. The upper Kibbey is a regressive shoreface deposit composed of fine grained sandstone at the northern and southern ends of the range. Mudstone and siltstone dominate in the center of the range where deeper water and lower energy conditions prevailed. Ultimately, the Kibbey shoreface transgressed out of the area and the Lombard facies was deposited in a partially restricted shelf lagoon. Shale and lime mudstone accumulated in the center of the range, to the north and south bioclastic wackestones, packstones, and grainstones were deposited in shoaling, higher energy conditions.

All three units of the group are thickest in the central Bridgers and thin north and south onto the Lombard arch and Wyoming shelf. Deeper water lithologies occur with the thick sections indicating that the central part of the range subsided relative to the Lombard arch and Wyoming shelf during sedimentation. A small positive trend in the central range trough is a local exception to the pattern. This paleotectonic pattern also operated during pre-Amsden uplift and erosion and thinned the group on the positive elements more. Evidence of similar paleotectonic influence on sedimentation along the structural weakness in the Bridgers is also found in Proterozoic and other Paleozoic rocks.

INTRODUCTION

Paleotectonic and Stratigraphic Setting of the Big Snowy Group

Regional Setting

Regionally, the stratigraphy of the upper Mississippian Big Snowy Group reflects the influence of major tectonic elements on sedimentation (Figure 1). It is reasonable to assume this relationship is also true on a local scale. This study attempts to document the influence of paleotectonic activity on sedimentation of the Big Snowy Group in the Bridger Range.

Most of Montana was the site of intermittent shelf or platform sedimentation on the Cordilleran platform throughout Paleozoic time (Sando, Gordon, and Dutro, 1975). The platform was bounded on the east by the transcontinental arch in eastern North Dakota and South Dakota and on the northeast by the Canadian shield. These were continually emergent areas which provided sediment for clastic deposition on the platform. The Cordilleran miogeocline bordered the Cordilleran platform on the west in extreme southwestern Montana, Wyoming, and eastern Idaho. Huh (1967) located and described the craton-miogeocline transition where Big Snowy Group shelf strata grade into equivalent miogeoclinal strata in extreme southwestern Montana. The miogeocline received sediments throughout Big Snowy time (Gutschick, Sandberg, and Sando, 1980).

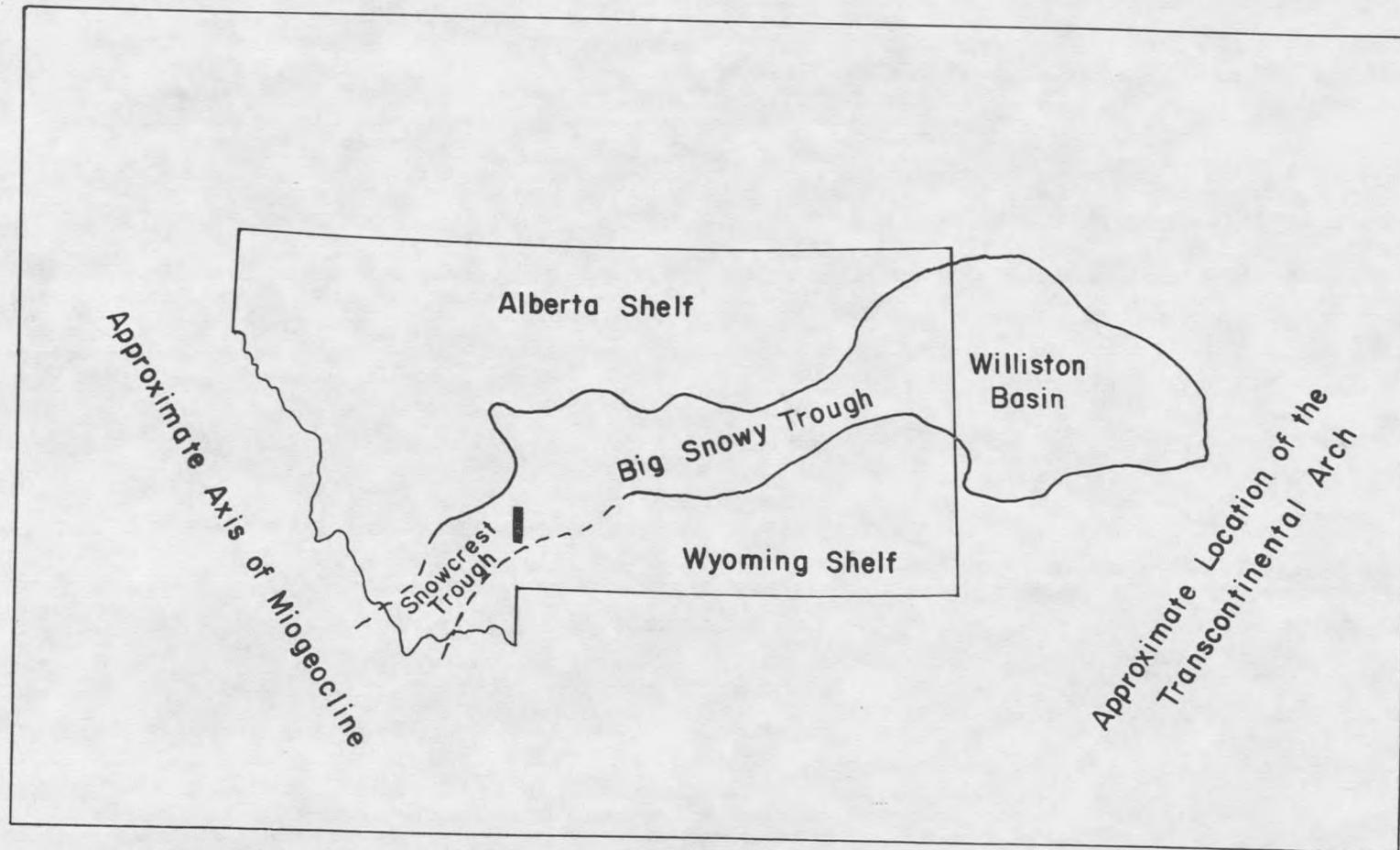


Figure 1. Late Mississippian tectonic elements on the Cordilleran platform in the northern Rocky Mountains.

Stratigraphic studies in Montana indicate that several smaller paleotectonic elements active within the Cordilleran platform itself were particularly influential on late Mississippian and early Pennsylvanian sedimentation (Sando, 1976; Peterson, 1981). An unstable trough connected the miogeocline with the Williston basin and divided the platform into several independent shelves (Figure 1). The east-west part of this unstable trend has been variously described as the Big Snowy basin (Eardley, 1962), Central Montana trough (Roberts, 1975), and Big Snowy trough (Peterson, 1981). Maughan and Perry (1967) named the southwest extension of this unstable trend the Snowcrest trough (Ruby trough of Peterson, 1980). The margins of both troughs correspond closely to the present zero edge of Big Snowy Group sediments (Figure 2). Previous authors have not always restricted usage of the terms Snowcrest and Big Snowy trough to late Mississippian rocks (e.g. Maughan, 1984; Roberts, 1979). In the present report the terms Snowcrest and Big Snowy troughs are used to indicate areas of active late Mississippian and early Pennsylvanian subsidence in which Big Snowy sediments were deposited and preserved.

North of the Snowcrest-Big Snowy troughs, the Alberta shelf was neutral relative to the actively subsiding troughs. Big Snowy rocks are not preserved there (Smith, 1972). Southward, equivalent upper Mississippian rocks are preserved on the Wyoming shelf. The rocks here are thin, however, indicating an intermediate degree of tectonic stability between the unstable Big Snowy and Snowcrest troughs and the Alberta shelf (Sando, Gordon, and Dutro, 1975).

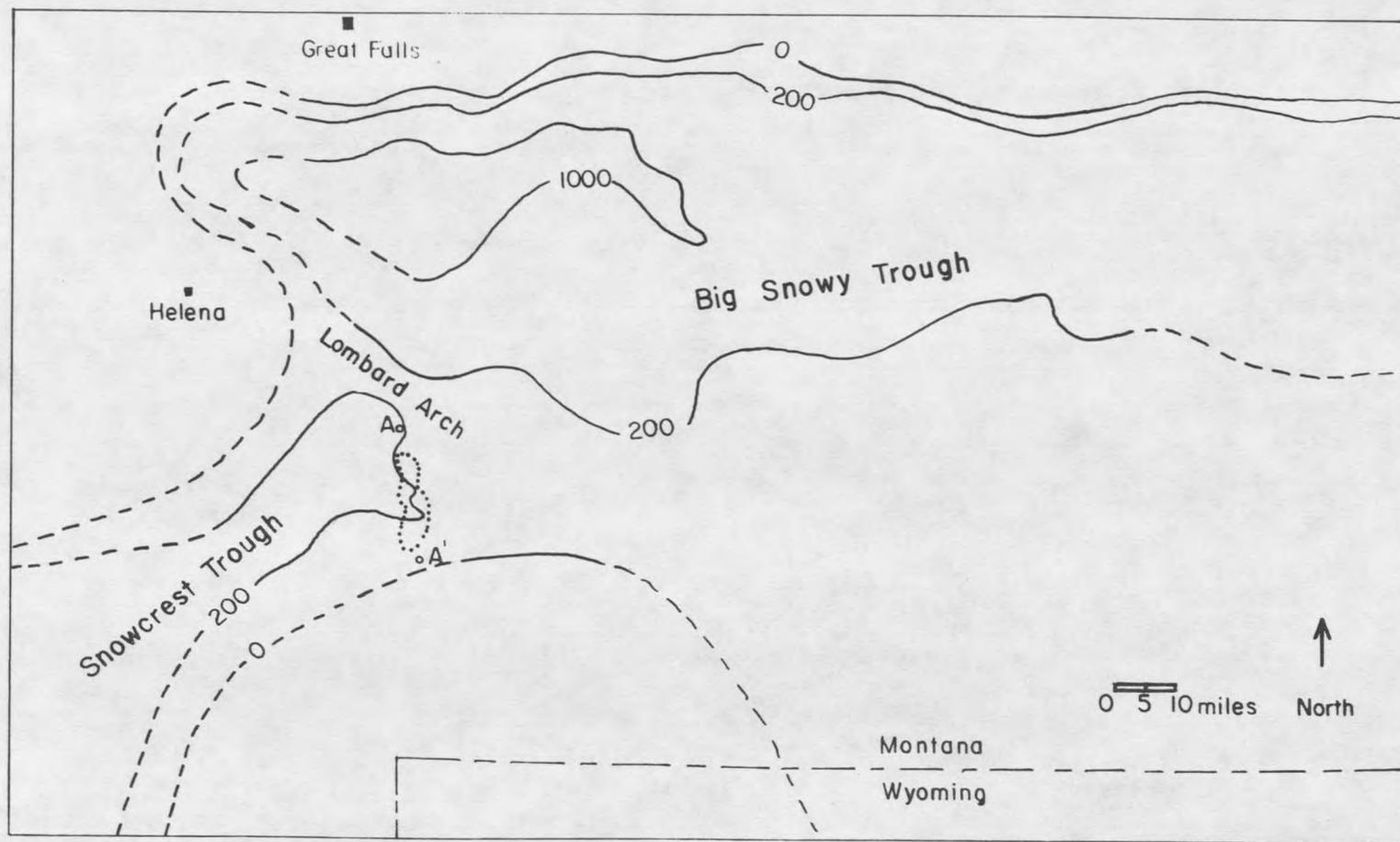


Figure 2. Isopach map of Big Snowy Group showing paleotectonic elements, contours in feet. See Plate I for section A-A', Bridger Range dotted. (modified from Harris, 1972).

Bridger Range Setting

A small positive element separates the Snowcrest trough from the Big Snowy trough (Figure 2). Big Snowy strata thin across this arch-like feature as they are traced from the Snowcrest trough to the Big Snowy trough (Blake, 1959; Harris, 1972). The term Lombard arch is applied in this report to the region between the Snowcrest and Big Snowy troughs where Big Snowy rocks are thin. This region extends approximately from Helena to Livingston, Montana.

Big Snowy Group rocks were first recognized in the Bridger Range by McMannis in 1951. He recognized extreme thickness changes in the group along the length of the Bridger Range. From a zero edge on the Wyoming shelf, which McMannis located in the southern Bridgers, the Big Snowy Group reaches a maximum local thickness in the central part of the range. The group then thins across the Lombard arch in the northern range.

Purpose

Geologists recognize that these thickness variations represent late Mississippian tectonic elements with either differential subsidence during deposition, post-Big Snowy differential uplift and erosion, or both (Harris, 1972; Sando, 1976; Maughan, 1984). Unfortunately evidence of depositional thinning, such as gradually shoaling lithofacies, is missing at previously studied locations due to post-depositional erosion. Thus, the original extent of the group and the relative importance of differential subsidence during

deposition and post-depositional erosion is unclear.

The present study was undertaken to determine if thickness variations of the Big Snowy Group in the Bridger Range are due to syndepositional movement of paleotectonic elements.

Study Area

The north-south trend of Bridger Range exposures provides a line of stratigraphic section across a late Mississippian structural trough approximately perpendicular to depositional strike. Also, the range is situated near the intersection of the Snowcrest and Big Snowy troughs which allows examination of the relationship between strata of both troughs as they thin and interfinger across the Lombard arch.

Paleozoic and Mesozoic rocks in the Bridger Range are uplifted approximately 1500 meters above surrounding valleys. They are also thrust several kilometers east (Dave Lageson, personal communication). The rocks of the Big Snowy Group are well exposed just east of the range crest which is composed of near vertical Madison Group limestone (Figure 3).

Fourteen exposures were analyzed along a line from just south to just north of the Bridger Range (Plate 1). The exposures extended from Rocky Canyon on the south end of the study area to a canyon on the Middle Fork of Sixteenmile Creek in the southern Big Belt Mountains on the north end. Thirteen exposures in the neighboring Horseshoe Hills, Southern Big Belt and Castle Mountains, and northwestern Beartooth Mountains were analyzed in less detail.



Figure 3. Exposure of upper Paleozoic rocks at southeast Sacajawea section (for location see Plate 1). Ridge on right is Mississippian Mission Canyon Formation, next left low interval with trees is Big Snowy Group, non-vegetated interval is Amsden Formation, cliff on left is Pennsylvanian Quadrant Formation.

Methods

During the field season of 1982, exposures of the Big Snowy Group in the Horseshoe Hills, southern Big Belt and Castle Mountains, northeastern Beartooth Mountains, and Bridger Range were located and briefly described. Many exposures were previously cited in the literature. Others were located with aerial photographs and reconnaissance. Literature research and correspondence with geologists working on this stratigraphic interval followed. During the field season of 1983 fourteen complete exposures of the Big Snowy Group in the Bridger Range were measured with a jacobs staff and described in detail. Several other incomplete or poorly exposed sections in the Bridgers were briefly described. Measurements and lithologic descriptions of each exposure are included in the appendix. Samples were collected at each significant lithological change.

Lithologic samples were slabbed and studied using a binocular microscope. Also, over 100 thin sections were prepared and analyzed with a binocular petrographic microscope. Approximately ten percent of the thin sections and slabs were stained with alizarin red solution to determine dolomite content.

Using these data, lithofacies were defined and interpreted. The lithofacies were then correlated between stratigraphic sections plotted on a stratigraphic cross section. Locations of measured sections discussed in the text are plotted on the location map on Plate 1.

The sections were plotted on the cross section shown on Plate 1

using the Big Snowy-Amsden contact as a datum. The contact was initially believed unconformable using field evidence. Conodont data later supported this conclusion and showed that this contact correlates with the regional Big Snowy-Amsden unconformity.

Although the surface is not necessarily a time line and may have had relief prior to Amsden deposition, it is the most appropriate datum for this stratigraphic interval. A line of synchronous deposition within the Big Snowy Group cannot be established unless significantly more biostratigraphic work is done. Therefore, an unconformity represents the next best alternative. The Big Snowy-Amsden unconformity shows the geometry of the underlying Big Snowy Group best. Also, this datum represents an established regional unconformity.

Samples for conodont age determinations were collected from carbonate rocks in the Big Snowy Group and overlying lower Amsden Formation. Sample locations were chosen in order to define the age relations of the Big Snowy Group and to aid in interpreting the contact with the Amsden Formation. Samples were restricted to less than one-third meter thick intervals of strata cropping out in relatively rich bioclastic limestone and dolomite. Eighteen one-kilogram samples were sent to the United States Geological Survey in Denver for preparation and analysis by Bruce Wardlaw. Sample locations and interpretations are included in the appendix with descriptions of measured sections.

PREVIOUS INTERPRETATIONS OF BIG SNOWY GROUP STRATIGRAPHY

Introduction

Three rock packages were deposited by three transgressive-regressive cycles during the Mississippian and early Pennsylvanian. In ascending order, these include the Madison Group, Big Snowy Group, and the Amsden Formation (Figure 4). The duration of the hiatuses separating each sequence is variable. In general, however, the farther from the unstable trough axis, the greater the duration (Smith and Gilmour, 1979). Although the groups are separated by regional unconformities or hiatuses, they are intimately related by common sedimentologic and tectonic controls. Some discussion of the Mission Canyon Formation below and Amsden Formation above the Big Snowy Group is necessary to understand the external tectonic and sedimentologic influences on deposition of the Big Snowy Group and bounding contacts.

Relations of the Big Snowy Group to the Underlying

Mission Canyon Formation

The Mission Canyon Formation ranges in age from middle Osage to middle Meramec (Sando, Gordon, and Dutro, 1975). The formation extends throughout Montana except where removed by Tertiary erosion. The diverse rock types of the Big Snowy Group contrast sharply with the underlying relatively uniform Mission Canyon carbonates. The

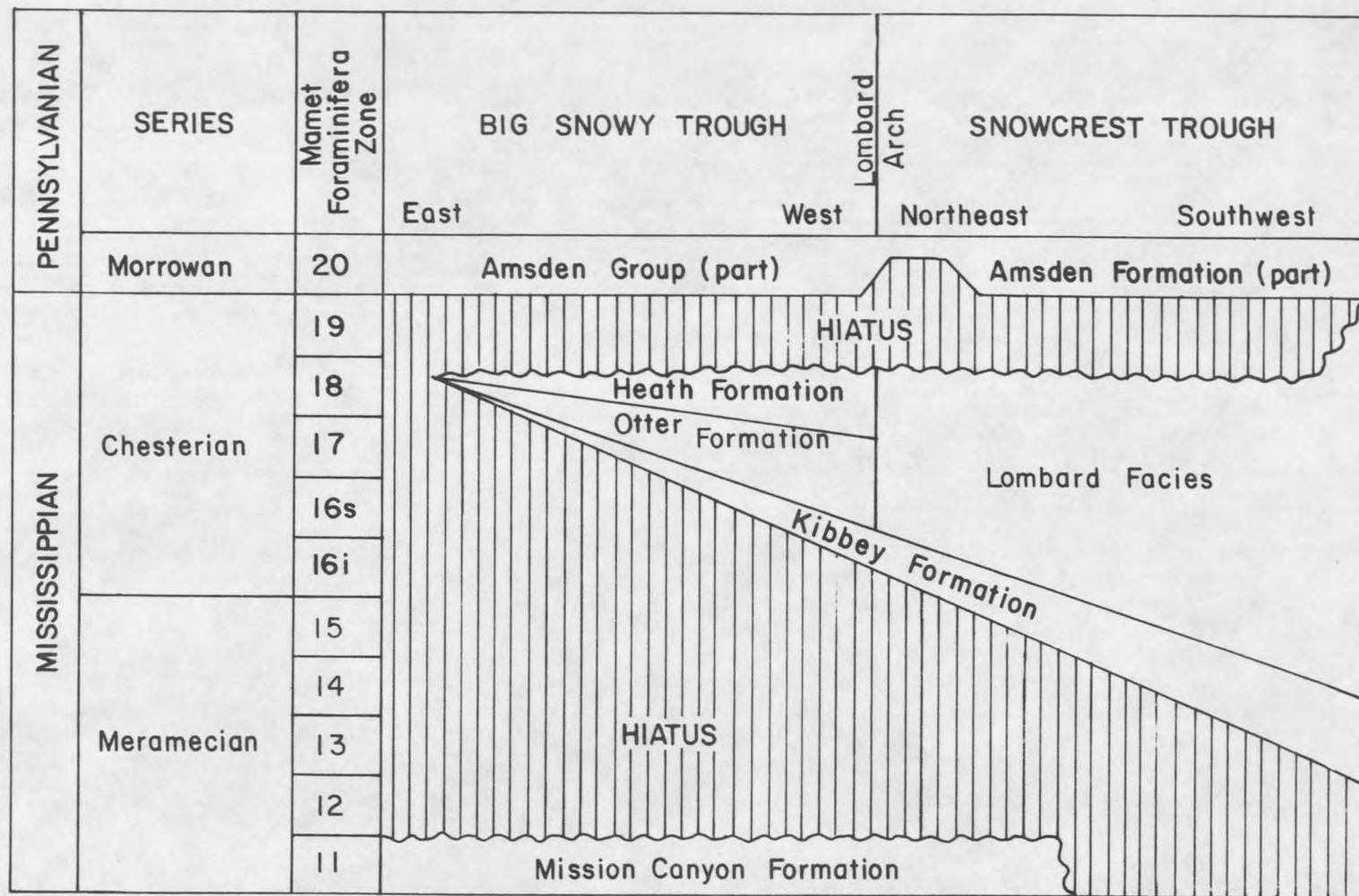


Figure 4. Stratigraphic chart showing temporal relations and nomenclature of the Big Snowy Group in Montana (modified from Sando, Gordon, and Dutro, 1975).

contrast is noticeable in outcrops in central and southwest Montana as a change from massive, gray Mission Canyon limestone ridges or cliffs to covered or partially covered red Big Snowy slopes. Where solution breccias and karst deposits are not developed near the top of the Mission Canyon Formation, the contact with the Big Snowy Group is placed at the change from massive, medium gray-brown lime or dolo-bio-wackestone to pastel muddy and silty dolostone, siltstone, or sandstone. Isopach maps indicate that thickness trends of the Mission Canyon Formation coincide closely with those of the Big Snowy strata; maximum Mission Canyon sections in the Big Snowy and Snowcrest troughs thin away from the trough axes toward both the Alberta and Wyoming shelves.

Dolostone and limestone are cyclically interbedded in the upper half of the Mission Canyon Formation with two or more major evaporite beds. Two or more solution breccia zones replace the evaporites in exposures in the ranges of southwest Montana. The lowermost breccia zone can be traced throughout most of the ranges in south-central Montana (Roberts, 1966; Sando, 1974). These solution breccia zones are composed of variably rounded dolostone clasts with angular chert clasts in a red-yellow, muddy, silty carbonate matrix. Evaporite breccia zones are laterally continuous but vary in thickness. The lower boundary is generally a distinct, continuous red clay bed. Clasts become less abundant upsection through the zone. Finally, the breccia gives way to fractured Mission Canyon limestone at the top of the solution breccia zones along a poorly defined, irregular boundary.

Research has shown that karst-like features are developed along the Mission Canyon-Big Snowy contact (Roberts, 1966; Sando, 1974; Maughan, 1984). Reddish breccia deposits fill collapsed caverns developed along joints and bedding planes on top of the Mission Canyon Formation. The karst deposits vary extremely in thickness and are discontinuous laterally. Evaporite breccias are laterally continuous and vary less in thickness.

The relation of karst formation to the overlying Big Snowy Group is disputed. Sando (1976) believes that the Mission Canyon-Big Snowy Group contact is regionally unconformable; between early Meramec time when Mission Canyon deposition ended and latest Meramec time when Big Snowy deposition began, the Mission Canyon Formation was exposed across Montana. In this model the karst deposits were produced by subaerial erosion. Evidence for the unconformity includes three, and possibly four missing faunal zones at the contact (Figure 4).

In contrast, Maughan and Roberts (1967) and Harris (1972) argue that the Madison Group and Big Snowy Group are conformable in the Big Snowy trough. They cite interfingering of lithologies across the contact as evidence. Further, Maughan (1984) states that since evidence of paleosol and other subaerial erosion features on the contact are missing in central Montana, a significant hiatus is not represented in the Big Snowy trough. He interprets the karst features to be a result of subsurface post-depositional collapse of basal Big Snowy sediments into solution zones in the Mission Canyon rather than subaerial erosion.

Although the Mission Canyon Formation and Big Snowy Group may be

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conformable in the Big Snowy trough, previous work in the Snowcrest trough indicates that this part of Montana was emergent prior to the Big Snowy transgression. Scott (1933), Walton (1946), Severson (1952), and Miller (1959) all reported erosional thinning of Mission Canyon limestone and development of erosional relief along the contact at different locations in southwestern Montana.

In summary, a complex combination of processes are thought to be responsible for development of solution breccias, karst deposits, and relief on the Mission Canyon-Big Snowy contact at different locations in Montana. There is disagreement on whether the contact is conformable in the Big Snowy trough. However, the contact in the Snowcrest trough and Bridger Range represents an unconformity with some form of erosion.

Big Snowy Group

History of Nomenclature

Big Snowy rocks were initially assigned to the Quadrant Formation which included strata between the Mission Canyon and Ellis Formations (Peale, 1893; Weed, 1896; Iddings and Weed, 1899). Weed (1900) subdivided the Quadrant Formation into the Kibbey Sandstone, Otter Shale, and an unnamed upper member and raised it to group status. He designated exposures in the Little Belt Mountains of central Montana as type sections for these formations. Scott (1935) established the Big Snowy Group in central Montana and included in it the Kibbey, Otter, and Heath Formations (Figure 4). The Heath was named for exposures in the Big Snowy Mountains of central Montana. Since then

the Big Snowy Group of central Montana has been expanded to include the top of the Mission Canyon Formation (Seager, 1942) and bottom of the Amsden Formation (Gardner, 1959). However, Scott's original terminology has been reinstated in subsequent reports (Maughan and Roberts, 1967; Sando, Mamet, and Dutro, 1969; Jensen and Carlson, 1972; Smith and Gilmour, 1979). Because members of the group were not formally delineated in parts of the Snowcrest trough, the Big Snowy was designated as a formation there (Maughan and Roberts, 1967; Smith and Gilmour, 1979).

The only detailed regional study of the Big Snowy rocks is an unpublished doctorate dissertation by Harris (1972). Most of the following brief description of the Kibbey, Otter, and Heath Formations is credited to Harris' regional study of upper Mississippian and lower Pennsylvanian rocks. His study was focused primarily on rocks in the central Montana area.

Big Snowy Trough

Harris divided the Kibbey Formation into three informal members. The lowest member consists of red shale with lenses and beds of sandstone and gypsum; the middle member consists of dolomitic limestone with gypsum beds; and the upper member consists of sandstone with interbedded shale and lenses of dolomite. Shale is the dominant rock type in all three members along the northern margin of the Big Snowy trough and sandstone dominates along the southern and southwestern margins and in the Snowcrest trough. Although the middle member is restricted to the Big Snowy trough, the lower and

upper members thin across the Lombard arch and continue into the Snowcrest trough with slight lithologic change.

The lower member of the Kibbey Formation is interpreted as a high energy shoreline deposit with associated fine grained intertidal and subtidal deposits (Ballard, 1964; Sando, 1976). Restricted circulation of the water caused by either relief on the Mission Canyon Formation, or minor sea level fluctuations, or both, is indicated by evaporite beds. The environmental conditions remained the same during deposition of middle Kibbey dolomitic limestone and evaporites, however the sand supply from the craton was diminished (Ballard, 1964). The upper member of the Kibbey is interpreted as sandstone deposited in similar high energy intertidal and shoreline environments (Ballard, 1964).

In the Big Snowy trough lithologies of the upper member of the Kibbey Formation grade into and intertongues with lithologies of Otter Formation over a three to five meter interval. This relationship is seen where the contact is exposed at Durfee Creek dome in the Big Snowy Mountains. Lenses of Kibbey sandstone intertongue with Otter shale three to five meters above the Kibbey sandstone beds (Harris, 1972).

The Otter consists of a lower green and gray shale with limestone and dolomite and an upper gray shale. Typical Otter lithologies thin and pinch out across the Lombard arch. With minor exceptions, they are not found in the Snowcrest trough. The lower carbonate was deposited in a more normal marine, sand free, intertidal and shallow subtidal environment offshore from the Kibbey (Harris, 1972).

Further offshore in relatively calm, subtidal water, shales accumulated. These conditions prevailed during the transition into the overlying Heath Formation shale and limestone.

The Heath Formation is the least aerially extensive formation of the Big Snowy Group. Dark, petroliferous shales are the predominant rock type in the axis of the Big Snowy trough. These grade south and southwest into sparsely fossiliferous, cherty, lime-mudstone with some quartz-sand grains on the Lombard arch. The shales accumulated in quiet, oxygen poor conditions in the central trough (Harris, 1972). Along the southern margin and Lombard arch, more agitated marine conditions prevailed proximal to a source of cratonic sand.

Snowcrest Trough

Farther southwest in the Snowcrest trough, stratigraphic relations of rocks equivalent to the Big Snowy Group of the central Montana are not well understood due to several factors. Most significantly, petroleum exploration has lagged far behind activity in central Montana where subsurface data is an integral part of stratigraphic understanding. Also, facies changes in the miogeocline-platform transition and telescoping of strata by eastward motion of thrust plates complicates interpretation. Geologists of the United States Geological Survey are beginning to piece together data in the Snowcrest trough but most of the ideas are as yet unpublished.

Stratigraphic study of Big Snowy age rocks in the Snowcrest trough began when Blake (1959) showed that the Otter Formation and

Heath Formation intertongue across the Lombard arch and become a single unit composed primarily of limestone. He tentatively proposed the term Lombard facies of the Heath Formation to apply to this unit. The name was chosen because the interval is readily accessible and well exposed near the abandoned Lombard railroad station 17 miles west-north-west of the Bridger Range.

McMannis (1951) first described this limestone in the Bridger Range and correlated it to the Heath Formation in the Big Snowy trough and to the section at Lombard. United States Geological Survey geologists working in the Snowcrest trough carry the Lombard facies and Kibbey Formation into the extreme southwest part of the Snowcrest trough. Both units are presently considered mappable as formations equivalent to the Kibbey, Otter, and Heath Formations of the Big Snowy Group (personal communication, Maughan, Wardlaw, 1983). The author also recognizes the Kibbey and Lombard strata as mappable formations in the Bridger Range equivalent to formations in the Big Snowy Group of central Montana.

Several lines of reasoning support the conclusion that the formations of the Big Snowy Group are in part, but not completely, time equivalent facies of each other (Figure 5). As mentioned previously, contacts between formations are gradational over considerable vertical distance and formation lithologies interfinger. Also, the lowest nearshore Kibbey Formation sandstone facies is the most aerially extensive, whereas the Lombard and equivalent Otter and Heath Formations are restricted to the trough axis. Similarly, the Kibbey Formation is thickest at the trough margins, and the Lombard

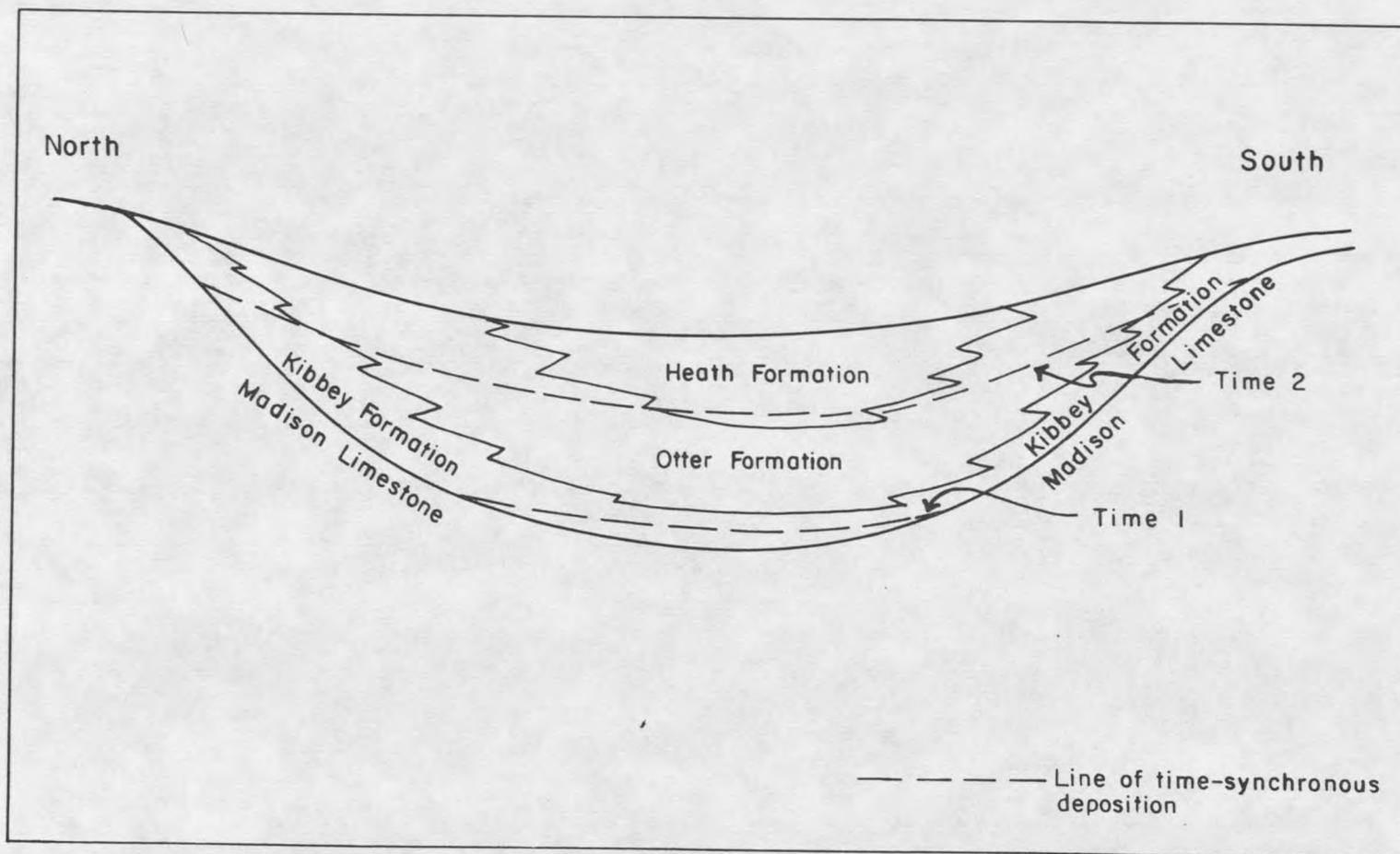


Figure 5. Cross section across Big Snowy trough: time-synchronous facies diagram (from Harris, 1972).

and Heath Formations are thickest at the trough axis (Maughan and Roberts, 1967; Harris, 1972).

Using biostratigraphic data, Sando (1974) determined that the Kibbey Formation is youngest near the miogeocline in the southwesternmost part of the Snowcrest trough (late Meramecian), and oldest in the easternmost part of the Big Snowy trough and the Williston basin (middle Chesterian) (Figure 4). He concluded that the Big Snowy Group represents a classic diachronous transgressive series. The sea initially transgressed into the Snowcrest trough from the miogeocline and deposited the Kibbey nearshore sandstone during late Meramec time. As the transgression continued, the Kibbey nearshore facies migrated regionally eastward and locally to the trough margins until middle Chester time. Simultaneously, the Lombard and equivalent Otter and Heath offshore facies followed behind the eastward transgressing shoreline but were restricted to the trough axis.

Relations of the Upper Big Snowy Group to the Overlying Amsden Formation

The Amsden Formation unconformably blankets the Big Snowy Group series (Maughan and Roberts, 1967; Sando, Gordon, and Dutro, 1975) (Figure 4). In the central part of the Snowcrest and Big Snowy troughs the Amsden overlies Lombard facies and Heath Formation respectively. Towards the trough margins, it rests on the Kibbey. On most of the Alberta and Wyoming shelves it rests on the Mission Canyon Formation. Extensive erosion prior to Amsden onlap in early

Morrow time is indicated by forty-five meters of relief between the Heath and Tyler Formations in central Montana (Smith, 1979).

The Amsden in the Snowcrest trough consists of a lower red mudstone and siltstone with some discontinuous sandstone, limestone, and dolomite beds. The red interval grades up into carbonate rocks with minor sandstones and evaporites. The former represents nearshore lagoonal and swamp deposits, the latter restricted marine offshore banks in a shallow sea (Sando, Gordon, and Dutro, 1975).

INTERPRETATION OF THE BIG SNOWY GROUP
IN THE BRIDGER RANGE

Introduction

In this chapter lithologic and stratigraphic data and interpretations from the study area are integrated into the regional relations previously discussed. Formations and members are described in sequence from oldest to youngest. A brief description of the contact with strata above and below the group is included. Each formation and member has an individual section in the text for lithofacies, depositional environment, and stratigraphic relations.

The Big Snowy Group in the study area is divided into the Kibbey Formation and Lombard facies (Figure 6). The Kibbey is further subdivided informally into a lower predominantly dolostone member, and an upper sandstone and siltstone member. These are approximately equivalent to the upper and lower members of the Kibbey Formations in Harris' (1972) statewide study. The Lombard facies overlies the Kibbey and is equivalent to the Otter and Heath Formations of central Montana.

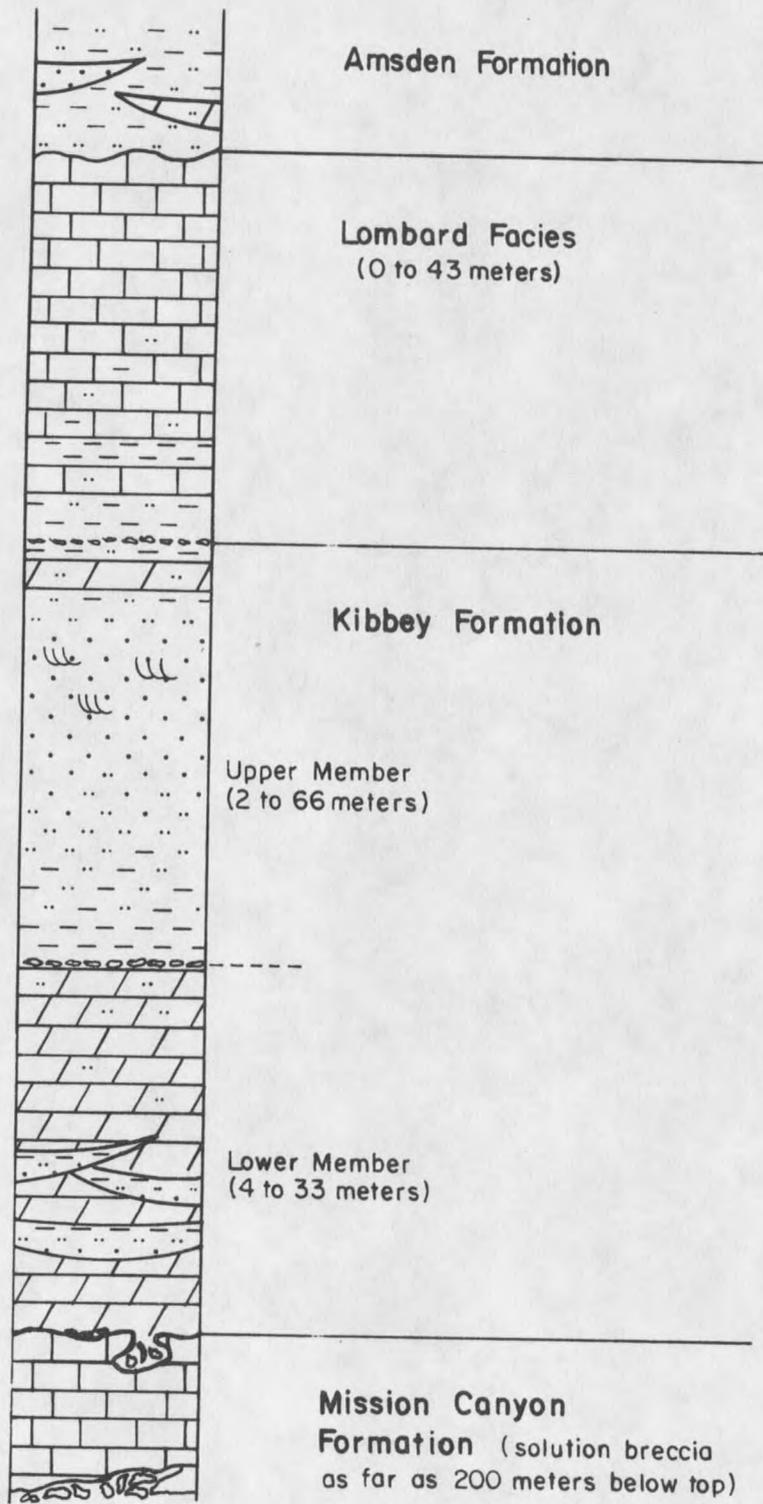


Figure 6. Generalized lithologic column of the Big Snowy Group.

Lower Big Snowy Group Contact and the Underlying
Mission Canyon Formation

Description

One or more solution breccia zones are present in the Mission Canyon Formation within 200 meters of the contact with the Big Snowy Group. The breccia zones are similar to those described by Roberts (1966). The breccias characteristically form less resistant zones within the Mission Canyon limestone and weather reddish-yellow. Approximately one meter of red clay defines the base of the breccia zones on a distinct contact with underlying limestone. The breccias are composed of various sizes of variably rounded dolostone clasts and minor brown angular chert in a silty, muddy, reddish-yellow carbonate matrix. The breccias grade up into fractured limestone at the top of the zones. At several exposures, an interval of undisturbed limestone separates two or more breccia zones. The thickness of the zones is variable at different exposures. Distance from the contact with the Big Snowy Group also varies. A breccia zone extends to within ten meters of the Mission Canyon-Snowcrest contact at station 191.

A karst sinkhole is developed along the contact at the Bridger Canyon section on the south end of the range. Unbrecciated Mission Canyon limestone encloses the six meter deep by twelve meter wide cavity which constricts to approximately one meter at the top. Siltstone and dolostone from the overlying Kibbey Formation fill the cavity. Various sized dolostone clasts have indistinct boundaries and appear contorted and squashed. A red muddy, silty dolostone

matrix supports the clasts in the cavity. The breccias in the cavity grade up into undisturbed Kibbey muddy dolostone just above the top of the cavity. At least the lower five meters of Kibbey Formation is bowed down towards the karst sink in the upper Mission Canyon Formation.

Identifying the contact of the Mission Canyon Formation and Big Snowy Group is straightforward at the exposures where solution breccias or karst deposits do not occur near the contact. The top of the Mission Canyon Formation is very similar to the type section at Logan, Montana and to the equivalent Bull Ridge member in the Beartooths. The primary rock type is fine to coarsely crystalline, medium brown-gray, oolitic, dolomitic, lime bio-wackestone with chert. Overlying the Mission Canyon Formation are muddy, silty, laminated, pastel colored dolostones with lenses of quartz siltstone and sandstone typical of the lower member of the Kibbey Formation. At the exposure at station 191 in the central Bridger Range a four meter thick conglomerate rests on the Mission Canyon Formation. The conglomerate is composed of sub-rounded pastel muddy dolostone clasts similar to the lower Kibbey Formation in a red muddy sandstone matrix.

The Mission Canyon-Big Snowy contact is not gradational vertically or laterally and rock types do not interfinger. At several exposures, between one and two meters of relief is developed along several tens of meters of the contact and dolostone, dolomitic siltstone, and sandstone chips similar to the enclosing Kibbey Formation fill low areas on the contact.

Interpretation

Solution breccias, karst deposits, and rock types associated with the Mission Canyon-Big Snowy contact in the Bridger Range pose interpretive problems similar to those where the contact is exposed at other ranges in south-central Montana. However, at no section in the study area was evidence for continuous deposition across the contact found. Rather, there is evidence for a period of erosion and change in depositional environment.

Nearly all the exposures observed have some degree of relief on the contact. Also, the thickness of the Mission Canyon Formation varies up to fifty meters across the range (McMannis, 1951). Unfortunately, insufficient evidence is available to determine whether subaerial erosion or subsurface solution of the Mission Canyon limestone is the most important process responsible for thickness variation and relief. However, two relationships suggest that at least some thinning of the Mission Canyon Formation was produced by erosion. First, where the Mission Canyon is thin, the solution breccia zones within it are found closer to the formation top than is usually the case. For example solution breccias, which are generally located 100 meters or more below the Mission Canyon-Big Snowy contact, occur within ten meters of the contact at station 191 where the Mission Canyon Formation is forty meters thinner than at neighboring sections (McMannis, 1955). The elevated occurrence of the evaporite solution zones is best explained by erosion of the limestone overlying the evaporite or evaporite breccia zones in an

area of slight positive relief during a period of exposure. Secondly, one of the thinnest sections of the lower member of the Kibbey Formation in the Bridger Range coincidentally is located at station 191 (Plate 1) suggesting that a positive tendency caused this erosion and influenced sedimentation during and following the Kibbey transgression.

Different environmental conditions below and above the Mission Canyon-Big Snowy contact are indicated by the sharp change from clean, oolitic, lime bio-wackestone to unfossiliferous, silty, muddy, laminated dolostone with intermittent basal lithoclast conglomerate. Lack of interfingering of the lithologies implies that a single extensive surface of disconformity existed.

In summary, evidence of erosion and change of depositional environment across the contact support a conclusion that the Mission Canyon Formation was exposed in the Bridger Range area prior to deposition of the lower member of the Kibbey Formation. The duration of time that the disconformity between the Mission Canyon and Kibbey Formation represents, however, can only be inferred since neither the upper Mission Canyon or lower Kibbey Formations are dated.

Lower Kibbey Member

Lithofacies

Introduction. The lower member of the Kibbey Formation is divided into two lithofacies. A laminated dolostone lithofacies extends throughout the study area. The second, a sandstone channel lithofacies is developed within the dolostone lithofacies in the

central Bridger Range (Figure 7). The channels interfinger with and grade into the laminated dolostone away from the central part of the range (Plate 1). The contact with the overlying upper member of the Kibbey Formation is placed below the first continuous mudstone or siltstone bed which correlates between exposures.

Laminated Dolostone Lithofacies. Siliciclastic and dolomitic mud and silt content within the laminated dolostone lithofacies increases up from a relatively clean dolostone on the lower contact with the Mission Canyon Formation to a dolomitic siltstone in the upper part of the member. Shades of maroon, pink, and yellow are common, with tan, green, and red shades less common. Coloration generally reflects variable amounts of clastic mud and silt, but alternating oxidation conditions are suggested by lighter and darker zones which occasionally cross bedding but generally are restricted to individual horizons.

Laterally persistent millimeter to centimeter thick laminations are present throughout the dolostone lithofacies (Plate 2). The laminations are variably resistant and weathering produces a sequence of alternating smooth and grainy surfaces. Locally they are continuous over a series of humps about two centimeters high and four centimeters long. In some places they are contorted into steep, small scale folds between relatively flat laminae. Dessication cracks, teepee structures, and calcite filled fenestral vugs and veins disrupt the laminations (Plate 3).

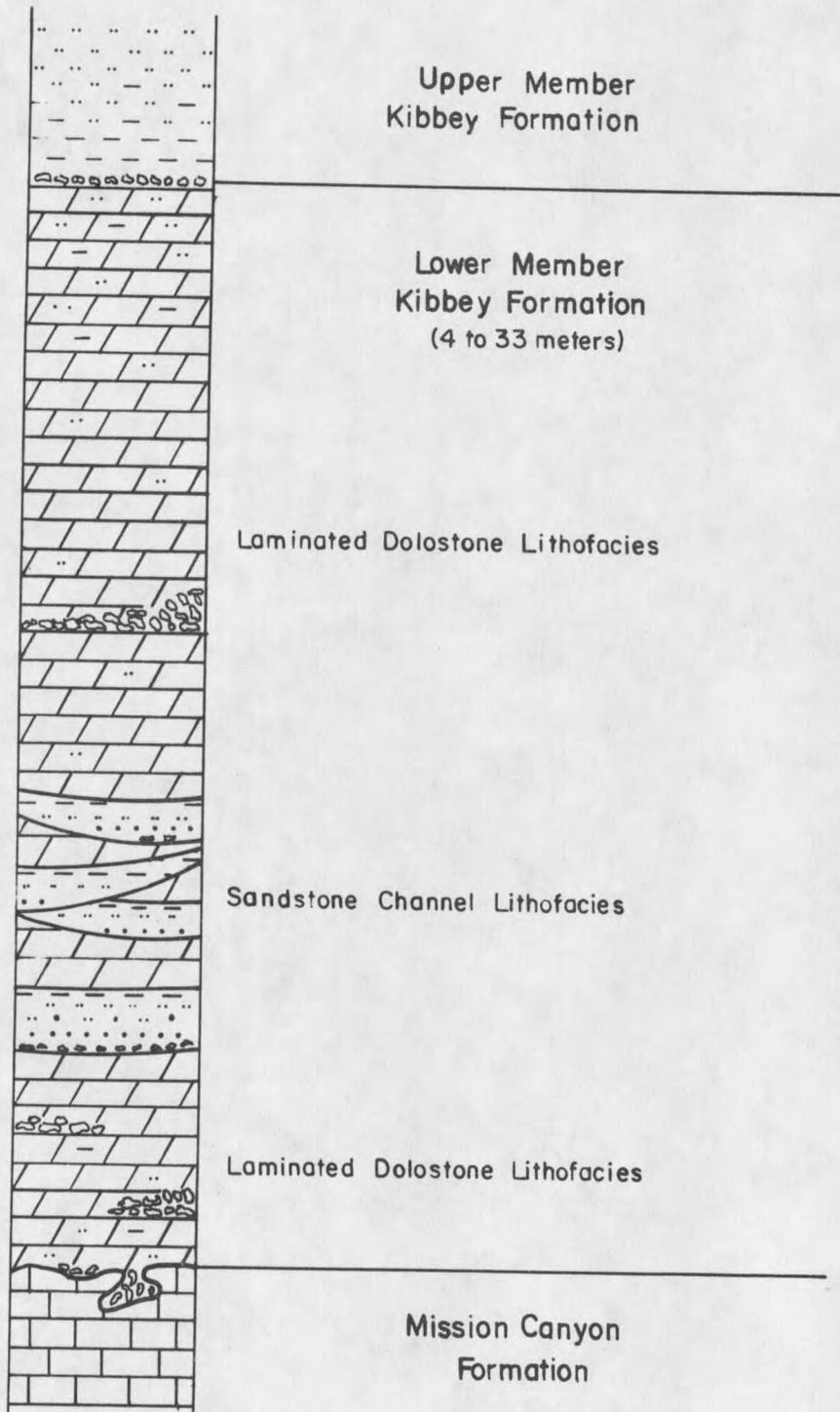


Figure 7. Generalized lithologic column of the lower member of the Kibbey Formation. See text for description of lithofacies.

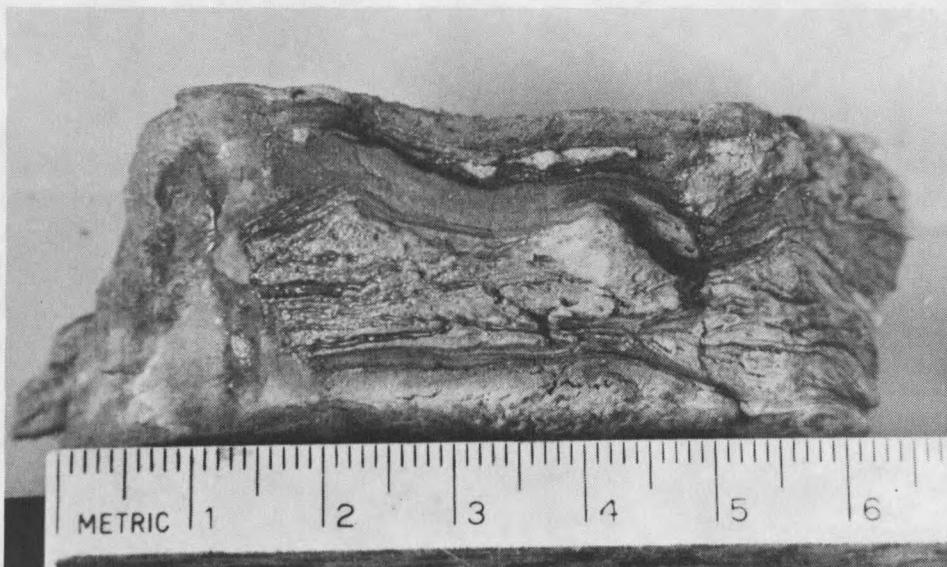


Plate 2. Photograph of laminated dolostone in the lower member of the Kibbey Formation. See text for discussion.

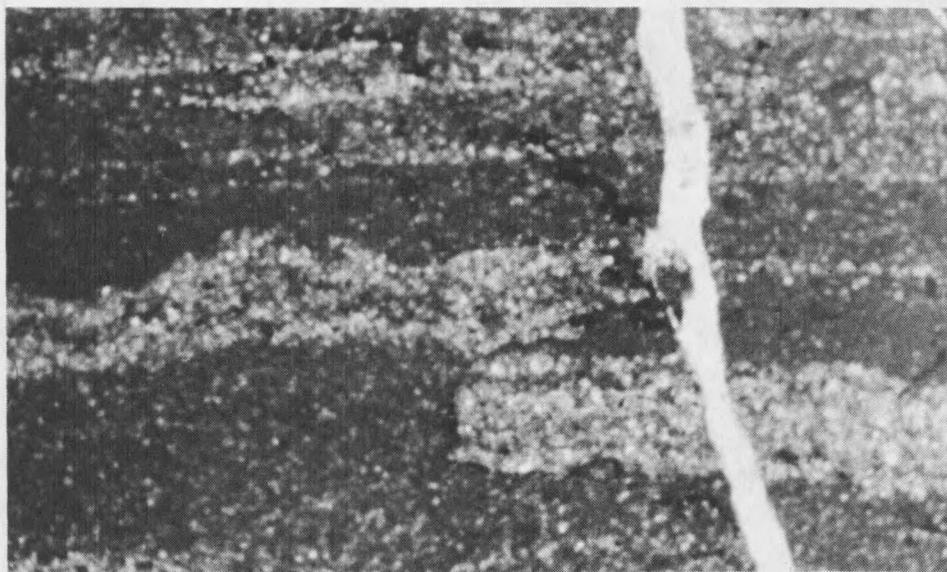


Plate 3. Photomicrograph of laminations, note the calcite filled fenestral fracture (approximately 2.5 mm across field).

Also within this lithofacies are dolostone breccias which grade laterally and vertically into undisturbed laminated dolostone. Although beds of breccia are up to two meters thick, centimeter to meter thick beds are typical. The millimeter to several centimeter diameter dolostone clasts are not graded or sorted. The boundaries of the clasts are indistinct and grade into the matrix (Plate 4). Upper and lower contacts of the breccia zones are also indistinct, and bed thickness varies along strike. Individual breccia beds do not extend between exposures.

Five thin sections representing both the laminated dolostone and dolostone breccias were analyzed. Dolomite appears as microspar sized crystals. In thin section laminations are preserved as millimeter to centimeter interlayering of zones rich in quartz-silt (Plate 3). By estimation, quartz silt content averages ten percent in the thin sections; individual laminations are significantly richer.

The laminated dolostone lithofacies is the most persistent facies of the Big Snowy Group in the Bridger Range and appears to continue out of the study area north and south. It is the only lithofacies present in the northern and southern parts of the study area. In the central Bridger Range, where the channel lithofacies is well developed, only thin beds of laminated dolostone are preserved above and below the channel lithofacies (Plate 1). An exception to this pattern occurs at the exposure at station 191 where the lower member of the Kibbey Formation is exceptionally thin; the channel lithofacies is absent and a four meter thick basal conglomerate rests

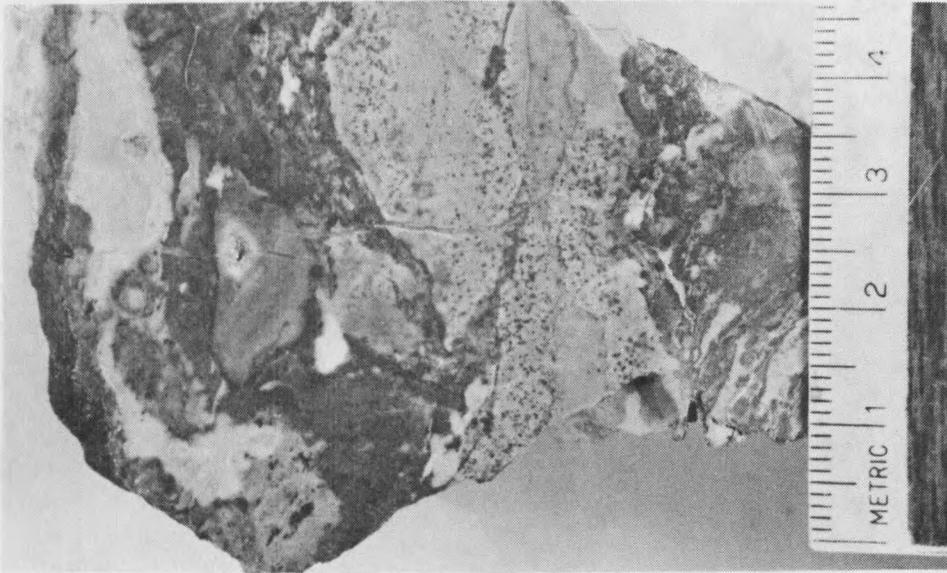


Plate 4. Photograph of solution breccia in the laminated dolostone lithofacies.

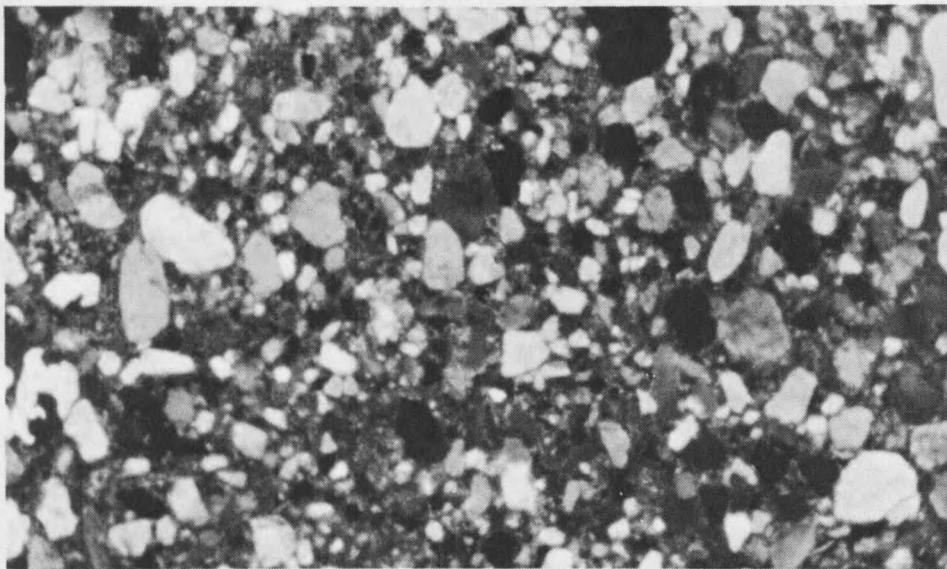


Plate 5. Photomicrograph of sandstone in the sandstone channel lithofacies (approximately 2.5 mm across field).

directly on the Mission Canyon Formation. The conglomerate is composed of sub-rounded clasts of sandstone, siltstone, and dolostone in a silty dolostone matrix. The conglomerate grades into the laminated dolostone and sandstone channel lithofacies to the north and south.

Sandstone Channel Lithofacies. Within the dolostone lithofacies in the central Bridger Range, lens-shaped channels of sandstone, siltstone, and mudstone are developed (Figure 7). This second lithofacies occurs as a series of up to six discrete upward-fining channels over a ten to twenty meter interval. Individual channels are not traceable between exposures, however the package is.

The sandstones, siltstones, and mudstones in the channels are a deep reddish color, typically brick red. Ideally an individual channel grades up from sandstone on a sharp contact cut into the underlying channel into siltstone and mudstone over a one to two meter interval. At some exposures, the channels fine up from a coarse siltstone rather than a fine sandstone at the base. Also, dolostone lithoclast conglomerates may be present at the base. If the channels are not directly superposed, a bed of laminated dolostone intervenes between them. In this instance, the overlying channel is cut into the dolostone. Other than grading, few bedding features are preserved. Fine siltstone and mudstone at the top of channels weathers to a blocky rubble fractured along sub-parallel surfaces one to four centimeters apart.

Eight thin sections were analyzed to determine mineral

composition and texture of the rocks in the sandstone channel lithofacies. Overall, the sand and silt is forty-five percent quartz, fifty percent dolomite, three percent chert, and two percent plagioclase. Minor hematite stains rims on the grains and imparts much of the characteristic red color. The dolomite occurs as variably rounded detrital crystals distributed evenly throughout the siltstone and sandstone and as medium size lithoclasts concentrated at the base of channels. Variable rounding of the dolomite crystals and integration of the crystals in the grain-supported sandstone framework attest to their detrital origin. Intergranular material is primarily siliciclastic mud with small amounts of carbonate which appears as patches of dolo-microspar.

The sandstone and siltstone exhibit bimodal distribution of very well rounded, low medium sand-sized quartz grains (.25 to .35 millimeter diameter) in a matrix of fine sand to silt-sized subrounded quartz grains and detrital dolomite crystals (Plate 5). The ratio of the fine sand and silt fraction to the medium sand fraction is four to one. Grain support without preferred orientation is typical. However, mud and matrix support become more abundant towards the top of the channel where the sandstone and siltstone grade into mudstone. Mud at the top of a channel is composed of about equal parts siliciclastic and carbonate components.

Depositional Environment Interpretation

Introduction. The two lithofacies in the lower member of the Kibbey Formation represent facies within a single depositional environment. The member is composed primarily of supratidal and high intertidal dolostones deposited on a sabkha. The occurrence of evaporite breccias in the dolostones indicates that the prevailing climate was hot and arid. The sandstone channel lithofacies represents intertidal channels (tidal creeks) in the nearshore marine environment marginal to the sabkha. Siliciclastic grains deposited in the tidal channels and trapped by algal films were derived from the neighboring shoreface environment where the upper Kibbey was contemporaneously deposited. Supratidal sedimentation dominated at the north and south ends of the range where the Mission Canyon surface was relatively elevated, whereas intertidal channel deposition was most important in the central range which was depressed. Station 191, which was a positive area within the central range, is an exception to this trend.

Laminated Dolostone Lithofacies. Work on modern and ancient sabkha environments has generated an association of sedimentologic features which are used to identify this environment in the record. Most important of these are dessication features, algal mats, fenestral fabric, lithoclast conglomerates, evaporites (or solution breccias), and lack of marine organisms (Lucia, 1972). The interpretation of the depositional environment of the lower Kibbey is based on occurrence of these indicators.

Clastic texture, presence of antigravity features such as steeply sloping laminae, and constant thickness of laminae over substrate irregularities rather than infilling in depressions and thinning over highs are reported as important criteria for recognition of mechanical binding of sediment by algal film (Ginsburg et al, 1954; Davies, 1970). Clastic texture is preserved in the Kibbey dolostones as alternation of laminations rich in coarse and fine silicic and carbonate grains. Laminations which are contorted into steep, small-scale folds in this lithofacies are examples of sediment bound by material which is cohesive enough to resist gravity. Finally, constant thickness of laminae over substrate irregularities is common in the laminated dolostone lithofacies of the lower member of the Kibbey Formation.

Detrital sediment trapped by algal films on modern tidal flats is mostly derived and transported from nearby marine environment by tidal and storm processes (Park, 1976). This appears to be the case for the silicic component of detritus trapped in the Kibbey dolostones since the abundance of siliciclastic material increases upsection as the marine environment simultaneously shifts landward over the tidal flat by transgression. Trapped carbonate detritus is primarily derived from the sabkha crust (Park, 1976).

Recognition of evaporites in outcrop is complicated because they can be leached to form solution breccias. Lucia (1972) states that correlation with subsurface evaporites and association with sabkha carbonates are the best criteria for confirmation that breccias are the product of evaporite solution. Both relationships are true for

the Kibbey Formation; evaporites are preserved in the lower member of the Kibbey Formation in central Montana (Harris, 1972), and the enclosing dolostones are interpreted as a sabkha deposit in the Bridger Range. Lucia (1972), also points out that dolostone is often partially leached during the evaporite solution process. This is evident in the Kibbey dolostone clasts in solution breccias. The contact between breccia clasts and matrix is gradational and indistinct. Finally, the deposits cannot be mistaken for conglomerate since evidence for fluid transport such as sorting or grading is missing.

Evaporite minerals in a sabkha are most likely preserved in the supratidal zone and in the transition between supratidal and intertidal zones (Shinn, Lloyd, and Ginsburg, 1969; Lucia, 1972). Further, extensive bedded and laminated evaporites precipitate out of standing water on the sabkha whereas nodular and replacement evaporites precipitate out of interstitial water beneath the depositional surface (Lucia 1972). Thickness and lateral persistence of evaporite solution breccias are more likely the result of the solution of evaporite beds rather than nodular evaporite zones. Nodular evaporite zones usually leach to form vugs which may subsequently be filled with calcite (Lucia, 1972). Features such as these are missing. Lens-shaped beds of evaporite precipitated out of water ponded on the Kibbey sabkha as the water evaporated. Standing water was probably ponded in depressions in the supratidal zone by storms and spring tides.

Mudcracks and fenestral vugs and veins disrupt the algal

laminations in the laminated dolostone lithofacies of the Kibbey Formation. Shinn, Lloyd, and Ginsburg (1969) reported that mudcracks on modern sabkhas are produced and most likely preserved in the supratidal and high intertidal zones. Shinn (1968) and others have documented that fenestral vugs and veins are also produced primarily on supratidal flats by shrinkage and expansion of sediments, gas bubbles from air escape during flooding, and wrinkles in algal mats. These data support the conclusion that the laminated dolostone lithofacies represents a supratidal and high intertidal sabkha environment.

Sandstone Channel Lithofacies. Tidal channels are intimately related to the sabkha. They generally reflect a seaward, intertidal component of the environment. Development of the channels in lower Kibbey algal dolostones signals the onlap of more marine, intertidal environments and sediments onto the low areas on the sabkha in the Bridger Range. The source of sediment in tidal channels is the shoreface environment and sabkha crust (Shinn, Lloyd, and Ginsburg, 1969).

Several detailed models of channel development in tidal flat and sabkha environments fit the lower Kibbey channel lithofacies. Shinn, Lloyd, and Ginsburg, (1969) documented that tidal channels on the tidal flats of Andros Island migrate laterally by point bar accretion in a similar manner to fluvial systems. The channels fine up from a basal channel lag derived from undercutting sabkha crusts, into sand, silt, and finally supratidal sediment. Most of the crossbedding

characteristic to the fluvial channels is lost to burrowing in the tidal environment. All these indicators are present in the sandstone channels. The channels cannot be confused with fluvial channels due to the intimate association with the laminated dolostone.

Stratigraphic Interpretation

The lower member of the Kibbey Formation algal dolostones and intertidal channels record the initial transgression of the sea onto the Mission Canyon Formation. The sea flooded into the Snowcrest trough and Bridger Range area from the Cordilleran miogeocline during earliest Chester time (Sando, 1974). Tides and storms washed enough water from the marine environment onto the sabkha flats to establish algal mats which in turn trapped detritus derived from the siliciclastic nearshore environment and carbonate sabkha crust. Evaporites precipitated from water intermittently ponded in depressions.

Tidal channels represent an intertidal, seaward component of the member. Supratidal sedimentation dominated on the north and south ends of the range and intertidal channel deposition was most important in the central range. Localization of intertidal deposition in the central Bridger Range (Plate 1) indicates that this area was depressed relative to areas south and north either prior to or during deposition of the lower Kibbey Formation or both. Two explanations are possible; both are based on subsidence localized in the central Bridger Range. First, a depression developed on the Mission Canyon Formation by tectonic instability in the central

Bridger Range prior to onlap of the sabkha facies. Alternately, the area was depressed by differential subsidence during deposition of the lower member of the Kibbey Formation. The only distinction between the two mechanisms is the timing of the subsidence relative to the Kibbey transgression. Therefore, it is reasonable to assume that both were partially responsible.

Stratigraphy and facies of the lower member of the Kibbey Formation near station 191 presents an exception to the interpretation of a single unstable area in the central Bridger Range. Deep erosion of the Mission Canyon Formation and thin conglomeratic deposition of the lower member of the Kibbey Formation at station 191 indicates that this was an area of positive relief following and possibly during Mission Canyon time, during deposition of the Kibbey Formation, and following. Thus, during part of Big Snowy time, the central Bridger Range was segmented into two unstable elements north and south of the station 191 area. Facies and thickness trends suggest that the conditions existed during Mission Canyon time (late Meramec), and persisted through Big Snowy time (late Chester), and possibly into Amsden time (early Morrow).

Pronounced thinning of the lower member of the Kibbey Formation in the southern Bridger Range (Figure 8; Plate 1) indicates that the area was relatively positive. Furthermore, supratidal and high intertidal conditions persisted throughout the lower Kibbey time there. This thinning and shoaling marks the transition from the relatively unstable Snowcrest trough onto the Wyoming shelf. The lower member of the Kibbey Formation extends out of the study area to

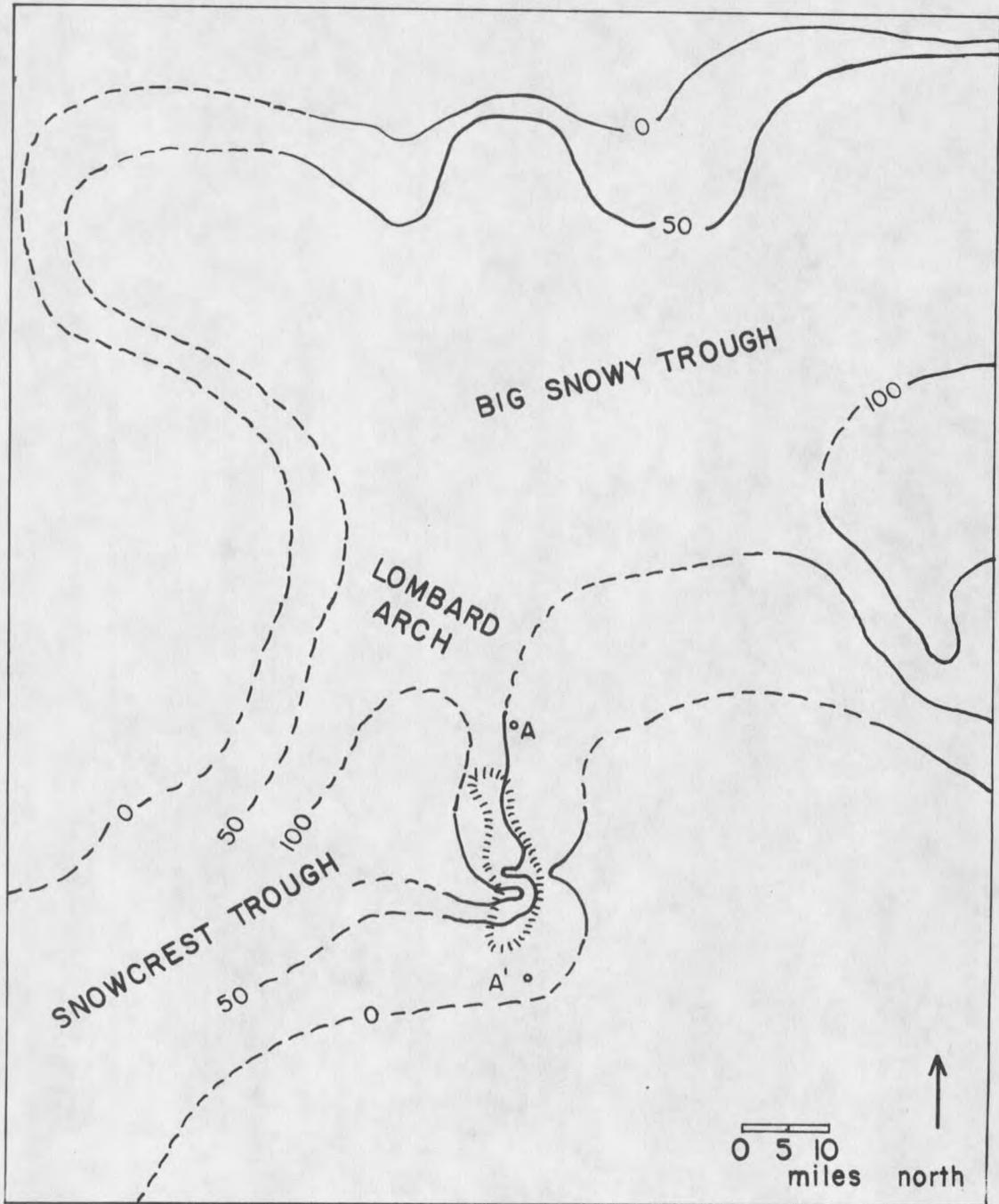


Figure 8. Isopach map of the lower member of the Kibbey Formation. Contours in feet, dashed where control is poor. Section A-A' depicted on Plate I. Bridger Range dashed. (adapted from Harris, 1972)

the south.

A similar thinning trend is seen to the north of the central Bridger Range. An isopach map of the lower member of the Kibbey Formation (Figure 8) shows that the thinning trend continues north out of the study area across the Lombard arch.

Upper Kibbey Member

Lithofacies

Introduction. The upper member of the Kibbey Formation extends across the entire study area, but like the lower member, thins north and south from a maximum thickness in the central Bridger Range (Plate 1). Sandstones and siltstones in both members also have very similar grain texture and mineralogy. The upper Kibbey member crops out as a relatively resistant tabular body and is divided into two lithofacies (Figure 9). Typically a thin basal conglomerate grades up into mudstone, siltstone, and sandstone through the lower two thirds of the member which is termed the sandstone lithofacies. Hematite imparts a red color to all but the middle sandstone which is characteristically pale reddish colored and crossbedded. The top one third becomes silty and muddy with beds of dolostone which weather reddish. At several sections another conglomerate at the top of the Kibbey Formation marks the contact with the overlying Lombard facies. Discussion of the upper member of the Kibbey Formation is divided into a section on the lower sandstone lithofacies and one on the upper mudstone-dolostone lithofacies.

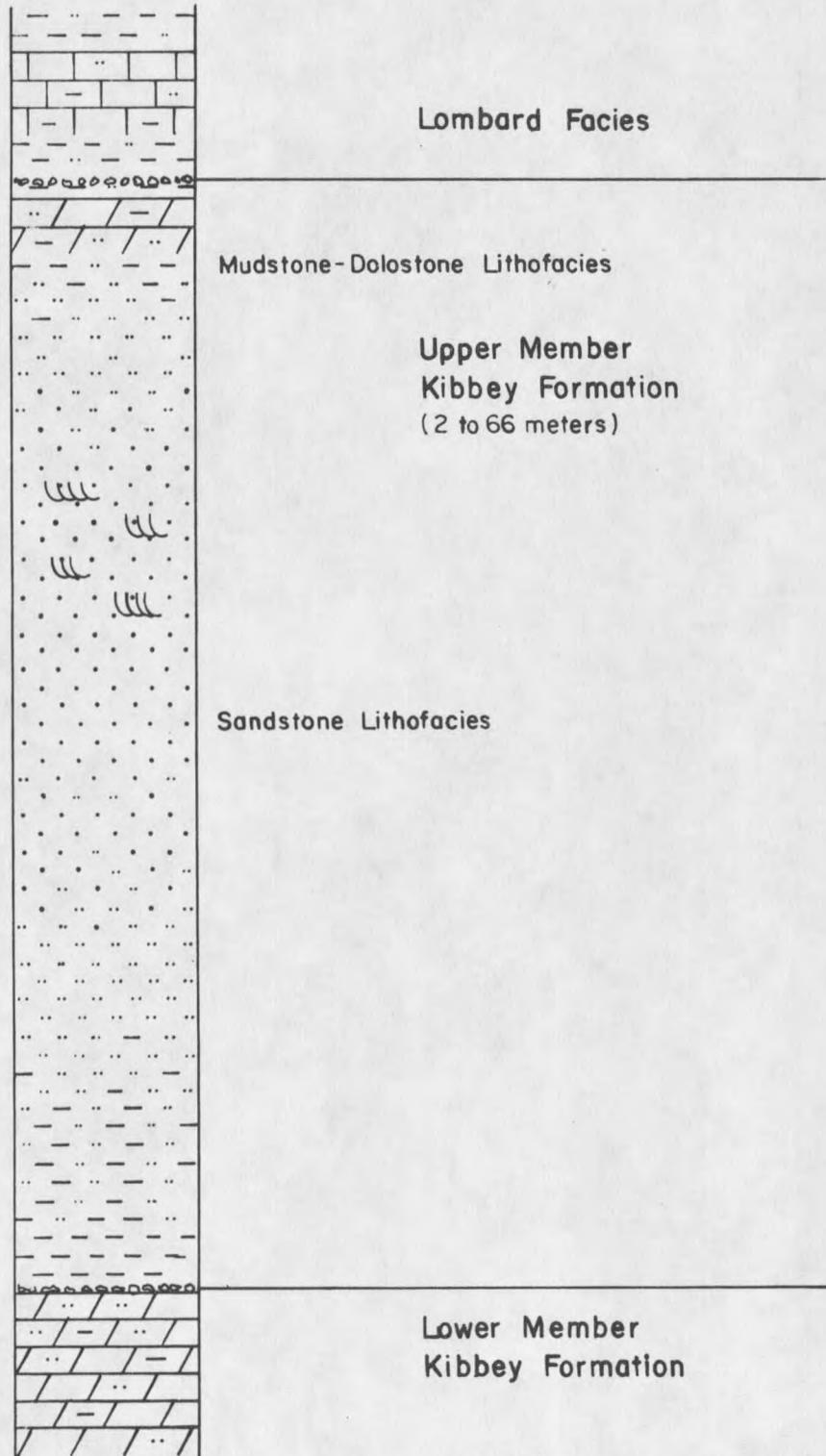


Figure 9. Generalized lithologic column of the upper member of the Kibbey Formation. See text for details of lithofacies.

Sandstone Lithofacies. At several exposures a reddish conglomerate at the base of the sandstone lithofacies overlies a sharp contact on the lower Kibbey muddy, silty, dolostone. Fine and medium grained sand supports sub-rounded sandstone, dolostone, and siltstone clasts up to ten centimeters in diameter in the conglomerate. At other exposures muddy red siltstone at the base of the upper member of the Kibbey Formation appears gradational with underlying lower Kibbey muddy, silty, dolostone.

Mud content decreases upsection in the sandstone lithofacies as red silty mudstone grades into siltstone and finally into a fine red sandstone. Mud content also decreases laterally away from the central Bridger Range sections. Tabular bedding in the sandstone lithofacies varies from ten centimeters to two meters thick. Also, a few ripple laminations are poorly preserved in this interval. The very fine sandstone continues to coarsen up into fine or medium sandstone and becomes pale yellow-orange, green, or white towards the top of the sandstone lithofacies. At most exposures a cross bedded sequence is preserved within this interval at the top of the sandstone lithofacies.

The North Angler exposure exemplifies this sequence. Lowest in the sequence is three to four meters of large scale trough cross bedded sandstone. Individual troughs are ten inches deep and three meters across. Forset laminae are concave and tangential. Trough axis trend approximately east-west. Maximum dip of the cross beds is to the south at fifteen degrees. Troughs are truncated on top by the next trough. Occasionally, poorly preserved ripple cross

stratification are superposed on the trough cross strata. Above the trough cross bedded interval is a lens shaped sandstone body with slightly coarser lower medium sandstone (.25 to .35 millimeter) fifty meters across by three meters thick. Parallel foresets dipping twenty five degrees to the south in the lower half of the trough are truncated on top by parallel laminated sandstone. Finally, two and one half meters of sandstone with four centimeter thick tangential planar crossbeds dipping fifteen degrees to the south caps the sequence. At most exposures only one of these crossbed types is preserved at the top of the sandstone lithofacies.

Mudstone-Dolostone Lithofacies. The sandstone lithofacies grades up into a second mudstone-dolostone lithofacies in the upper member of the Kibbey Formation through an interval of increasing mud, silt, and dolomite content with a corresponding decrease in grain size. This upper lithofacies is a mixture (about equal amounts) of red-maroon sandstone, siltstone, and mudstone, with some dolostone beds developed towards the top at sections in the South Angler area. In contrast to the sandstone lithofacies, lateral thinning of individual beds indicates they are discontinuous. The dolostone is pale reddish, lavender, or pink and is occasionally mottled pale green. Irregular lumpy bedding and thin, wavy, crinkly laminations are characteristic. The contact with Lombard facies limestone is placed below the first dark gray limestone or shale. At several sections a thin mud chip conglomerate appears just below the contact.

Petrography. Analysis of thirty-five thin sections of the two lithofacies indicates the siliciclastic sandstone and siltstone grains are mineralogically and petrologically uniform throughout the upper member of the Kibbey Formation. However grain size, intergranular mud content, and detrital dolomite content varies regularly. Grain size increases upsection from basal silty mudstone to fine or medium sandstone in the upper sandstone lithofacies, then decreases to siltstone with some mudstone and dolostone in the mudstone-dolostone lithofacies. Inversely, intergranular mud decreases up through the lower lithofacies and increases upsection in the upper lithofacies. Detrital dolomite crystal content follows this same trend.

Bimodal texture is ubiquitous in coarse siltstone and sandstone in the upper member of the Kibbey Formation (Plate 6). Similar to the intertidal siltstone and sandstone of the lower member of the Kibbey Formation, a small component (about twenty five percent) of relatively coarser quartz grains are evenly distributed through the fine sand and silt. Grains are sub-rounded except for the larger fraction which is very well rounded. Intergranular matrix support is common except in the top of the sandstone lithofacies where cross bedding occurs. Interlayering on a millimeter to single centimeter scale of coarser and finer fractions of sand is apparent on about half the slides (Plate 6).

In some cases this stratification reflects alternation of grain rich and intergranular mud rich layers. Also, both types of

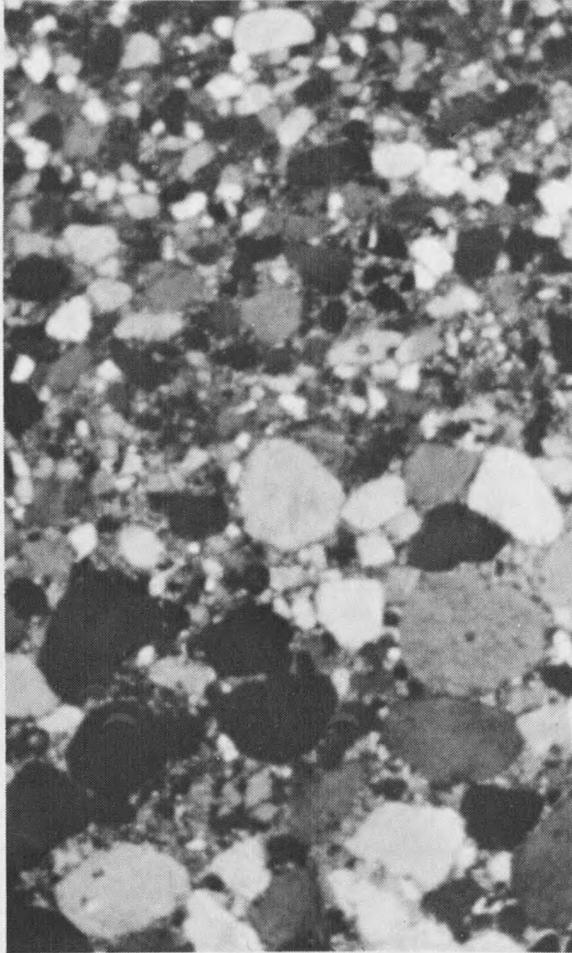


Plate 6. Photomicrograph of sandstone in the upper Kibbey sandstone lithofacies, see text for discussion (approximately 2.5 mm across field).

interlayering are graded in part. Strong parallel orientation of elongate grains is apparent on about half the slides.

Mineralogically the upper Kibbey sand grains vary little and are much like the intertidal sandstone channel and siltstone below except that detrital dolomite crystals are significant at the top and bottom of the upper member of the Kibbey Formation. Typically grains are ninety two percent quartz, five percent chert, and three percent unaltered plagioclase plus microcline in equal portions. Detrital dolomite crystals reach fifty percent at the base of the sandstone lithofacies and in the detrital beds of the dolostone lithofacies. The dolomite is present as variably rounded dolomite crystals or rhombs and sparse lithoclasts. Zircon and mafic minerals constitute a trace to one percent of the upper member of the Kibbey Formation.

Depositional Environment Interpretation

Introduction. The upper member of the Kibbey Formation overlies supratidal sediments of the lower Kibbey and underlies subtidal offshore marine sediments of the Lombard facies. The upper member represents a shoreface transition between these environments in the transgressive Big Snowy Group.

The upper member sandstone is underlain and overlain by mudstone. This lithologic sequence reflects changing hydrodynamic conditions within the shoreface-shelf environment in response to facies transgression and regression.

Mudstone is deposited by suspension in calm, low energy

conditions, and sandstone primarily by traction in higher energy conditions. Low energy conditions in the shoreface environment are located either in the subtidal lower shoreface-offshore shelf environment or nearshore tidal flats and lagoonal environment (Reinech and Singh, 1975).

Thus, the upper Kibbey shoreface sandstones can be classified as either transgressional or regressional. The terms transgression and regression refer to migration of a shoreline in a landward and seaward direction respectively (Curry, 1964). Transgressional shorelines leave a nearshore to offshore sedimentary record whereas the reverse is true for regressional shorelines. Determination of whether the upper member of the Kibbey Formation represents a transgressive or regressive deposit depends on the interpretation of the depositional environment of the mudstones which lie above and below the sandstone.

Features of the lower mudstone in the upper member of the Kibbey Formation sandstone lithofacies suggest an offshore origin. The mudstones are laterally continuous as is expected in the extensive offshore setting. Also, regularly layered and graded siltstones typical of this interval in the upper member of the Kibbey Formation are reported primarily from the offshore shelf and lower shoreface where tidal currents are active (Reinech and Wunderluch, 1968).

Features of the mudstone-dolostone lithofacies above the sandstone suggest a nearshore tidal flat and lagoonal origin. Mudstone, siltstone, and dolostone beds are laterally discontinuous and interfinger with each other as would be expected from a

nearshore deposit. Based on the same reasoning used for similar dolostone in the lower Kibbey member, thin laminations and irregular bedding in dolostones above the sandstone represent intertidal and supratidal conditions similar to those of the lower Kibbey member. These relationships suggest that an offshore-nearshore sequence is represented.

Further evidence supports the conclusion that the upper member of the Kibbey Formation is a regressive deposit within the transgressive Big Snowy Group series. First, the grain size trend and sedimentary structure sequence in this member fit the regressive offshore-nearshore facies model as proposed by Reinson (1983). Also, Klein (1974) states that regressive sequences have a higher preservation potential relative to transgressive sequences. As evidence he points out that along modern transgressive coastlines, only a thin basal transgressive interval, commonly with a conglomerate, is preserved beneath regressive sediments. Other studies of modern transgressive shorelines indicate that few facies of the shoreline are preserved during transgression (Swift, 1975; Schwartz, 1967). They are eroded in the high energy upper shoreface and beach zones as the facies shift landward. The transgression is recorded as a disconformity underlying shoreface or shelf sediments. Clifton (1973) reported that these erosional surfaces have very low relief but can be recognized by thin conglomerates with clasts derived from underlying sediments. The amount of erosion is variable and depends on proximity to zones of erosion along the disconformity.

In summary, most evidence suggests that the upper Kibbey sandstones are regressional. The conglomerate above and below are interpreted as erosional disconformities generated during the landward shift of facies. Where conglomerates are missing, minor transgressive sequences may be preserved.

Sandstone lithofacies. The conglomerate at the base of the lower member sandstone lithofacies represents a thin transition between the lower Kibbey intertidal-supratidal algal dolostone environment and an offshore to lower shoreface subtidal silty mudstone environment. As the Kibbey strandline environments shifted over the lower Kibbey supratidal sabkha and intertidal channels, siltstone, sandstone, and dolostone were ripped up and integrated into the lower sandstone lithofacies as conglomerate clasts and sand-sized grains.

Mudstones with interlayered muddy siltstone and sandstone overlying the conglomerate were deposited in an environment which was far enough offshore that suspension sedimentation dominated. Sand and silt are deposited during ebb and flood currents and the mud settles out during slack water (Reinech and Wunderluch, 1968). The offshore mud and silt thins north and south from a maximum in the central Bridger Range indicating that quiet offshore conditions persisted longer in the middle of the range relative to areas north and south.

Upsection in the sandstone lithofacies, the change from silt and mud dominated rocks back to sand and silt dominated rocks signals a

change from suspension to traction sedimentation. Increase in grain size and corresponding decrease in mud content upsection in the sandstone lithofacies is evidence of the increasing hydrodynamic regime associated with the shoreface environments. The trend continues as middle and upper shoreface zones prograde over the lower shoreface.

Large scale trough cross stratification with superposed ripples, the lowest occurrence of cross bedding in the sequence, is commonly attributed to the middle and upper shoreface zone where longshore bars and troughs develop in the surf zone (Campbell 1971; Howard, 1972; Land 1972; Reinech and Singh, 1975). Continued increase in hydrodynamic energy upsection is evidenced by complete winnowing of fine grained material from sandstone and also increasing grain size near the top of the sandstone lithofacies. Lens shaped bodies with parallel high angle foreset cross bedding and planar laminated sands are developed at the top of the sandstone lithofacies. Davidson, Arnolt, and Greenwood (1976) described similar bodies on modern bar crests in the surf zone of the upper shoreface. Finally, smaller scale and lower angle tangential planar cross beds at the top of the sandstone lithofacies are interpreted as a continuation of the regressional trend. Howard and Reinech (1979) report that similar cross bedding is produced in the shallow, high energy upper shoreface along modern coastlines.

Mudstone-dolostone Lithofacies. The mudstone-dolostone lithofacies above the sandstone lithofacies is a continuation of the gradual regressional shoaling trend. The laterally discontinuous silty mudstones were deposited by suspension in quiet water in lagoons or ponds, hematitic silts and sandstone lenses in intertidal and tidal channels, and dolostone beds on intertidal and supratidal flats. Wavey, crinkly laminations and irregular lumpy bedding in the dolostone may be algal mats and rooted zones respectively. Maughan (personal communication, 1984) interprets similar structures at the top of the Kibbey Formation at the Lombard section as a rooted zone in pluvial sediments.

The mud chip conglomerate at the contact with the Lombard facies records a landward shift of the shoreline. In this case the transgression superposed Lombard Facies mud and limestone on the mudstone and dolostone at the top of the Kibbey Formation. Transgressive deposits other than the conglomerate are not recognized between the nearshore rocks at the top of the Kibbey Formation and the offshore Lombard facies rocks.

Stratigraphic Interpretation

The upper member of the Kibbey Formation represents a predominantly regressive offshore-nearshore sequence within the transgressive Big Snowy Group. Below and above the member at several locations are minor disconformities generated during episodic landward shifts of facies by shoreface erosion. Transgressive

sequences may be present, particularly where an erosional disconformity is not recognized, however they are insignificant in relation to the upper Kibbey sandstone.

While in detail several thin stratigraphic sections do not fit the general trend, the upper member of the Kibbey Formation is thickest in the central Bridger Range (Figure 10; Plate 1). The member thins north and south onto the Lombard arch and Wyoming shelf. As previously noted, the upper Mission Canyon Formation and lower member of the Kibbey Formation also follow this trend. As indicated by localization of the lower Kibbey intertidal channel lithofacies, deeper environments persisted longer in the central Bridger Range relative to areas north and south during upper Kibbey time. These coincident relationships indicate that the central Bridger Range continued to be depressed relative to areas north and south.

Subsidence focused in the central Bridger Range during upper Kibbey time resulted in thicknesses of this member four times that of equivalents on the Wyoming Shelf in the southern map area and twice that to the north near the Lombard arch. For example, the member is approximately sixty meters thick at the South Angler section in the central range area. It is thirty meters and ten meters thick respectively at the Middlefork Sixteenmile and Rocky Canyon sections.

To the south of the central Bridger Range the member thins to nearly zero under the Lombard facies at Menard Creek (Plate 1). If thinning here resulted from pre-Amsden erosion, Lombard facies rocks would necessarily be completely removed. Preservation of the Lombard facies limestone indicates that this is not the case.

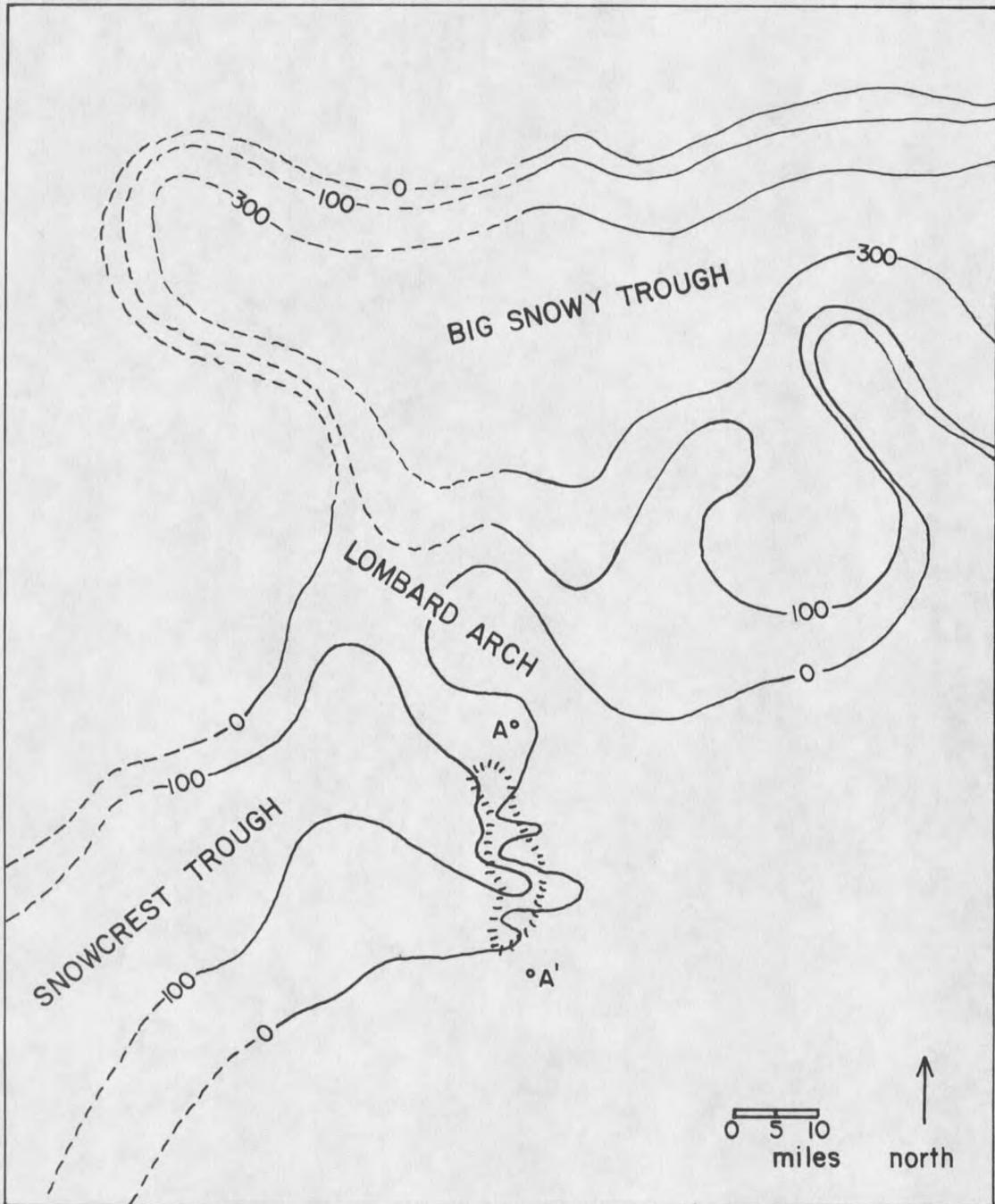


Figure 10. Isopach map of Lombard facies and Heath Formation. Contours in feet, dashed where control is poor. Section A-A' depicted on Plate I. Bridger Range dashed. (adapted from Harris, 1972)

Rather, the exceptional thinning at Menard Creek is attributed to either a localized positive tendency during upper Kibbey time or deeper shoreface erosion during the next transgression or both. The upper Kibbey extends south of the Menard Creek section at approximately six meters thick (Figure 10).

Previous studies have not extended the Kibbey Formation south of Bridger Canyon (McMannis, 1951; Harris, 1972; Sando, 1975). Several lines of evidence indicate, however, that a thin stratigraphic section of Kibbey Formation is in fact preserved under the Amsden Formation at the southernmost two exposures in the study area. First, at both the Bridger Canyon and Rocky Canyon sections two red silty, sandy intervals are separated by a thin Lombard facies limestone and white dolostone respectively, suggesting that both the Kibbey Formation and Amsden Formation are present. At both sections a thin red clay zone is present at the base of the second red of the Amsden Formation suggesting that an unconformity is developed. Also, the lower red sandstones and siltstones in the south are petrographically identical to the Kibbey Formation in the central Bridger Range.

North from the central Bridger Range, the member thins to about thirty meters at Horse Mountain and Middle Fork Sixteenmile and continues out of the study area. Isopachs for the upper member of the Kibbey Formation show that it remains less than fifty meters thick across the Lombard Arch and rapidly thickens again into the Big Snowy trough (Figure 10).

Most of this variation in thickness was caused by continued

subsidence in the central Bridger Range relative to the Wyoming shelf and Lombard arch during upper Kibbey time as previously discussed. The central Bridger Range subsidence is a local manifestation of the regional tectonic development of the Snowcrest-Big Snowy unstable trend.

Apparent episodicity of transgression at the top and bottom of the sandstone lithofacies within the Big Snowy Group transgressive series may be a direct result of episodic subsidence. Alternatively, episodicity may reflect changing rates of input of clastic detritus within a framework of continuous sea level rise as Harris (1972) suggested for the upper member of the Kibbey Formation in the Big Snowy trough. Most likely, episodic strand line shifting was produced by a combination of regional sea level rise and subsidence (Sando, 1974), changing rates of detrital sediment input (Harris, 1972; Ballard, 1964), and local subsidence in the central Bridger Range which was possibly episodic.

Lombard Facies

Lithofacies

Introduction. Mudstone and limestone of the Lombard facies overly a minor disconformity on the upper member of the Kibbey Formation produced during transgression of the Big Snowy Group sea. An excellent exposure of the Lombard facies near Ross Peak is the thickest (fifty-three meters) and the most complete section in the Bridger Range. Thickness of the Lombard facies is again coincident with thickness trends in the upper Mission Canyon and Kibbey

Formations. At sections north and south from the central Bridger Range, the Lombard is missing or thin due to either pre-Amsden erosion or depositional thinning with associated facies changes on the Lombard arch and Wyoming shelf. The Ross Peak section is very similar to the proposed type section of the Lombard facies at the Lombard railroad station, although the type section is slightly thinner (45 meters).

At the exposure near the Lombard station, the lower one third of the Lombard facies is composed of black fissile shale with a few limestone beds. This grades up into a middle lime bio-packstone and wackestone interval and upper sparsely fossiliferous lime mudstone interval.

At Ross Peak, the section is divided similarly into three lithofacies; a lower shale lithofacies with some beds of lime mudstone, bio-wackestone, and packstone, a middle bio-wackestone-packstone lithofacies with minor dark shale and lime mudstone interbeds, and an upper lime mudstone lithofacies with a few bio-wackestone beds (Figure 11).

Approximately thirty thin sections representing all three lithofacies of the Lombard facies at different locations in the Bridger Range were analyzed. The petrographic data and field data are integrated in the following discussion of these three lithofacies.

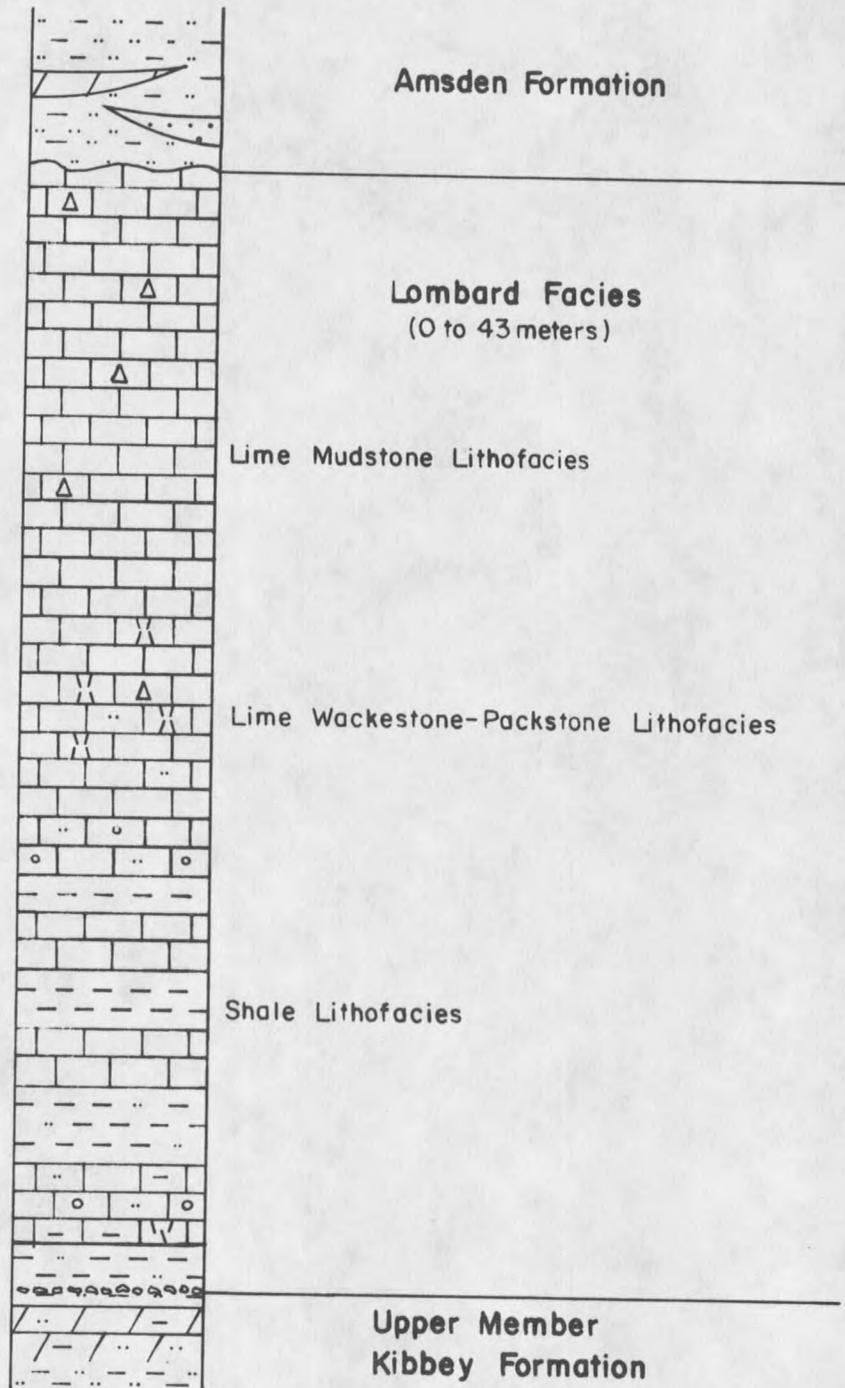


Figure 11. Generalized lithologic column of the Lombard facies. Circles denote crinoid packstone, vertical dashes denotes spicule wackestone. See text for details of lithofacies.

Shale Lithofacies. The shale lithofacies crops out as three or fewer limestone beds between covered zones at the base of the Lombard facies. Black-brown soil cover with grass and minor black silty shale float are typical of dark shale exposures in the study area. The lowest limestone outcrop consists of thick beds of dark gray to brown lime bio-wackestone, lime bio-packstone and lime mudstone. Packstones are composed primarily of crinoid ossicles, shell fragments, unidentified spicules or brachiopod spines, and quartz silt and sand in minor quantities. Wackestones differ in composition; the spicules or spines are dominant with crinoid ossicles and other clasts in minor amounts. Allochems are without preferred orientation, sorting, grading, or rhythmicity. Above this, one or two other outcrops within the shale lithofacies are medium bedded gray and brown lime mudstone which weathers orange-yellow. A peculiar mottled texture and two centimeter horizontal tubes on bedding surfaces suggest bioturbation.

Bio-wackestone-packstone Lithofacies. The shale grades into lime mudstone at the base of the middle bio-wackestone-packstone lithofacies. About four meters into this lithofacies are several one meter thick massive black-brown lime bio-packstone beds. The base of each bed is sharp on underlying lime-mudstone. The packstone is similar to those in the shale lithofacies except that there is strong parallel orientation of elongate grains and some crude millimeter and centimeter scale grading. Upsection in the bio-wackestone-packstone lithofacies is an interval of thinly interbedded black shale and

sparsely fossiliferous lime mudstone which grades into a sequence of bio-wackestones and packstones interbedded with lime mudstone at the top of the lithofacies. Again, wackestones are composed primarily of spicules or spines and packstones primarily of crinoid ossicles.

Lime Mudstone Lithofacies. At the top of the Lombard facies is about ten meters of thin to medium bedded lime mudstone in the upper lime mudstone lithofacies. The lime mudstone is cream-pink and olive-brown, with pods and small lenses of brown chert. Solitary corals were collected at several exposures of this lithofacies. A one meter thick foraminiferal bed with a packstone texture occurred two meters from the top at Ross Peak (Plate 7). Uniserial, biserial, and coiled forms of forams constitute sixty percent of the clasts, with spines or spicules as minor components. No grading or parallelism of grains was noted.

Depositional Environment Interpretation

Introduction. Subtle changes in clastic input and carbonate deposition of the Lombard facies signals slight changes in the depositional environment upsection, however all three lithofacies were deposited in similar environmental conditions. Features of the shelf-lagoon standard facies belt (Wilson, 1975) are present in the Lombard facies. Dark lime mudstone with sparse bio-wackestone and packstone are indicative of a quiet, subtidal environment in which bioclastic debris is washed in by intermittent currents to produce the characteristic textural inversion. Tidal processes may be

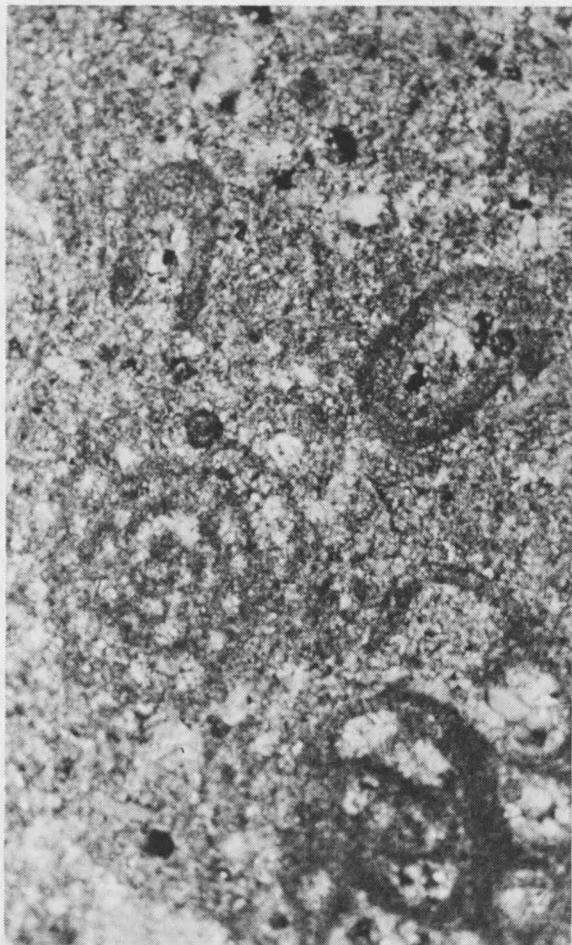


Plate 7. Photomicrograph of foraminiferal packstone in the Lombard facies (approximately 2.5 mm across field).

responsible for some transport of debris, although few obvious channel features are recognized and the mud-biocl原因 rich interbedding is not even or regular as might be expected if tidal currents were responsible. More likely, storm currents, possibly combined with tidal currents are responsible.

As defined by Wilson (1975), the shelf-lagoon lies within a carbonate platform behind a fringing barrier on the platform edge which partially restricts water circulation in the lagoon. Regional studies show that the Snowcrest and Big Snowy troughs were a lagoonal connection between the Cordilleran miogeocline and the Williston basin epeiric sea during Lombard time (Sando, Dutro, and Gordon, 1975). Environmental conditions became increasingly restricted eastward from the miogeocline in the Snowcrest and Big Snowy troughs. Based on isopach data, Rose (1976) concluded that a shelf edge topographic high in extreme southwestern Montana partially restricted circulation of the Lombard facies sea in the Snowcrest trough. The shelf edge is characterized by high carbonate productivity (Wilson, 1975) and probably provided a significant source for detritus washed into the Lombard facies shelf lagoon.

Further eastward in the Big Snowy trough, water circulation was even more restricted and carbonate input diminished (Harris, 1972). Studies in modern environments show that some degree of reducing conditions and water restriction can be produced by size and geometry of epicontinental lagoons (Logan and Cebulski, 1970). Water in long, linear lagoons are not mixed by circulating currents normally found in large bodies of water. Lack of water circulation leads to the

development of an anoxic lower layer and relatively normally oxygenated upper layer. Williams (1983) suggested that the Heath Formation shales were deposited in anoxic conditions below a stratified water column in such a lagoon. The Lombard arch probably also contributed to restricted circulation of marine waters with carbonate detritus east of the Snowcrest trough.

The thickest and most complete stratigraphic sections of the Lombard facies in the central Bridger Range provide a framework for interpretation of the environmental conditions during deposition of the three lithofacies of this unit. Quiet water carbonate shelf lagoon conditions persisted here. Incomplete sections north and south where two or fewer lithofacies are developed reflect the positive tendency of the Lombard arch and Wyoming shelf during and immediately following Lombard time. The three lithofacies are incompletely developed or missing north and south of the central Bridger Range either because of shoaling, more agitated environmental conditions or pre-Amsden erosion removed the upper ones.

The contact between the shoreline sandstone, mudstone, and dolostone at the top of the Kibbey Formation and the Lombard facies shales and limestones is the sharpest lithologic change in the Big Snowy Group. Sedimentation changed from upper Kibbey nearshore clastic to a quiet, subtidal, carbonate lagoon environment with very little coarse clastic input. Shoreface sandstones are not recognized between these environments. However, at some exposures a conglomerate is present here. The conglomerate is interpreted as an erosional disconformity developed during the transgression. Where

the conglomerate is missing from this interval, minor transgressional deposits may represent this transgressional facies shift. The change is attributed to a strandline shift brought about by regional sea level rise and regional subsidence combined with subsidence localized in the central Bridger Range.

The difference between the Lombard facies transgression and the lower Kibbey-upper member of the Kibbey Formation transgression is that the offshore environment of the Lombard facies was characterized by mudstone and lime mudstone deposition rather than by silty mudstone deposition in the Kibbey Formation offshore environment. Both rock types are interpreted as a product of suspension sedimentation in quiet lagoonal water. This suggests either that the high energy clastic shoreface was shifted farther away from the Bridger Range area during the Lombard transgression resulting in farther offshore environments there or that the offshore Lombard environment was deeper and quieter due to more acute subsidence in the Bridger Range. Also, carbonate deposition was established in the offshore environment at this point. This is attributed to trapping or mantling of siliciclastic detritus near the shoreline and introduction of carbonate detritus and carbonate producing organisms.

Shale Lithofacies. The dark shale and limestone of the Lombard shale lithofacies are an indication of a much lower energy environment offshore from the Kibbey shoreface sandstones. Regional sea level rise and subsidence caused transgression of the Kibbey Formation shoreface environment regionally eastward in the

Snowcrest-Big Snowy troughs and locally towards the trough margins. At the same time the mudstone lithofacies of the Lombard facies followed behind but was restricted to the deeper water in the subsiding trough axis (Sando, Gordon, and Dutro, 1975). In the Bridger Range the Ross Peak and South Angler areas were characterized by the greatest amount of subsidence during this time as evidenced by maximum thickness of offshore mudstone (Plate 1).

As the transgression continued, carbonate deposition spread out across the Bridger Range area following behind the transgressing Kibbey Formation shoreface environment. Minor amounts of quartz silt and sand in the lower Lombard facies mudstone lithofacies were derived from the Kibbey Formation lower shoreface clastic environment and transported offshore into the lagoonal environment soon after transgression.

This relationship suggests that the clastic shoreface was not mantled during lower Lombard time. Rather, the Lombard lagoonal environment and Kibbey shoreface coexisted laterally. The lack of carbonate allochems typically produced in intertidal carbonate environments, such as oolites and lithoclasts, supports the conclusion that the Lombard facies shoreline was siliciclastic, one in which carbonate production was precluded.

The spicules or brachiopod spines which are the dominant clast in wackestones were either indigenous or nearly indigenous to the Lombard facies environment or were carried into the environment by regular currents. In contrast, crinoid ossicles are present in significant quantities only in the less commonly occurring packstones

where they are the dominant clast. Thus, the packstones were either generated by more severe currents or were proximal to tidal channels or shoals where currents were strong enough to deposit bio-clasts without significant quantities of lime mud.

Direct evidence of bioturbation was observed at several sections in the lower shale lithofacies as worm tubes or burrows and mottling. Indirect evidence for bioturbation is provided by lack of preferred orientation or grading of clasts in the lower lithofacies. Bioturbation indicates that benthonic organisms were established in relatively normally oxygenated water at this time (Jenkyns, 1978).

Bio-wackestone-packstone lithofacies. The bio-wackestone and packstone lithofacies in the middle of the Lombard facies is similar to the shale lithofacies below except that shale and silt content is decreased and limestone content increased. This signals the establishment of widespread carbonate deposition in an environment with little siliciclastic input. Apparently the Kibbey shoreface continued to shift farther landward or it was finally mantled by extensive carbonate seas.

Carbonate grains and mud deposited in shelf lagoons are generated primarily in somewhat agitated, more normal marine areas marginal to the lagoon and carried in by tidal and storm currents (Wilson, 1975). In addition to the distal shelf edge source, the Lombard arch and Wyoming shelf probably provided a local source of carbonate detritus. Bioclastic components in packstones and wackestones indicate that spicules or spines were relatively common,

indigenous components of this lithofacies environment, and crinoid debris was washed in and deposited only as packstones by infrequent storm or tidal currents.

Direct evidence of bioturbation is missing in the bio-wackestone and packstone lithofacies. Primary depositional texture of wackestones such as grading and sorting and strong parallelism of elongate grains also indirectly suggests that bioturbation was precluded in this environment. This indicates that the lagoon had become at least intermittently anoxic since benthic organisms were previously established in the lagoon.

Like the Heath Formation shales, other Paleozoic black shales in the United States are interpreted to have been deposited under a stratified water column (Potter, Maynard, and Pryor, 1982). By analogy with other black shales and correlation with the Heath Formation, the lower Lombard facies may also be interpreted to have been deposited under an intermittently stratified water column. The depth, size, and geometry of the shelf lagoon also was partly responsible for restricted water circulation and anoxic conditions.

Lime Mudstone Lithofacies. Continued sea level rise combined with basin subsidence resulted in deposition of the lime mudstone lithofacies at the top of the Lombard facies in an even quieter, farther offshore or deeper water environment. A marked decrease in the number of wackestone and packstone beds and corresponding increase in lime mudstone reflects decreasing intensity and frequency of storm and possibly tidal currents due to either distance from

shore or a deepened lagoonal setting. Bioclasts are similar to those in the lower lithofacies except for the one foraminifera packstone near the top of the Lombard facies at Ross Peak. Quiet water had become seasonally or continually stratified. Upper layers could support pelagic forams, but the bottom layer was somewhat reduced as evidenced by lack of benthic fauna.

Stratigraphic Interpretation

As the Kibbey Formation nearshore environment overlapped eastward in the Snowcrest trough, the offshore Lombard facies mud and limestone environment followed. Transgression was caused by continued regional subsidence and sea level rise. In the study area the Ross Peak and South Angler areas in the central Bridger Range experienced the greatest amount of subsidence during Lombard time (Figure 12). The lowest Lombard shale lithofacies signals introduction of lagoonal conditions into the local axis of the Snowcrest trough. During deposition of the shale lithofacies shallower environments existed to the north and south of the central Bridger Range. As transgression continued, the lagoonal environment spread across the range. As a result, deeper environments persisted and thicker sequences are preserved in the central Bridger Range.

Most conodont samples collected from the Lombard facies in the Bridger Range yielded a late Chesterian age (written communication, Wardlaw, 1983) (see Appendix for location and interpretation of conodont samples). Samples from the base of the unit at the

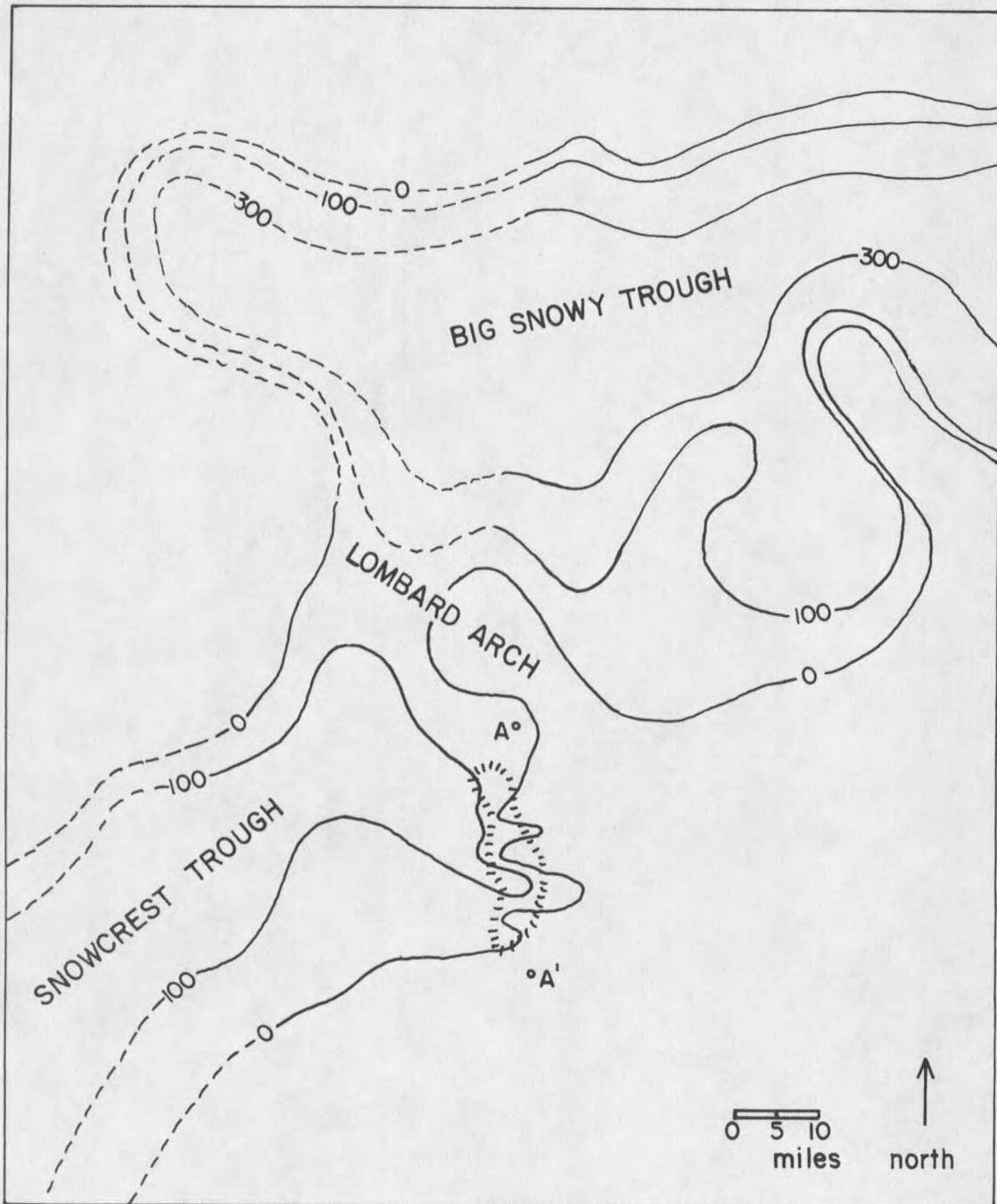


Figure 12. Isopach map of Lombard facies and Heath Formation. Contours in feet, dashed where control is poor. Section A-A' depicted on Plate I. Bridger Range dashed. (adapted from Harris, 1972)

Ross Peak and Maynard Creek sections however, were designated only as Chesterian. This indicates that the Lombard facies in the Bridger Range is primarily late Chesterian. However, one can speculate that the base may be slightly older at the Ross Peak and Maynard Creek areas.

The thickness variation of the Lombard facies in the Bridger Range is the result of a combination of differential subsidence during deposition and erosion after deposition. As previously discussed, the central part of the range experienced more subsidence than the Lombard arch and Wyoming shelf during deposition of the Kibbey Formation. In general this trend continued into Lombard facies time.

The exception to this general pattern is seen between Ross Peak and Bighorn Lake (Plate 1). Here the Lombard facies is missing and the Kibbey is relatively thick. Two hypotheses may be postulated to explain this difference. First, the entire central Bridger Range subsided as a trough during Kibbey Formation time, but during Lombard facies time the area between Ross Peak and Bighorn Lake became positive and Lombard rocks are missing due to non-deposition. In this case the present configuration reflects development of two depositional lows during Lombard time. A second possibility is that the central Bridger Range was an integrated depositional trough throughout Kibbey and Lombard deposition. Later, during pre-Amsden erosion, the area between the Ross Peak and Bighorn Lake became uplifted relatively more than the rest of the central Bridger Range. In this case, the configuration reflects pre-Amsden uplift and

erosion.

Isopachs of the Heath Formation and Lombard facies indicate that thinning north of the central Bridger Range continues onto the Lombard arch (Figure 12). Although this is partly attributed to pre-Amsden erosion (Klemme, 1949, Harris, 1972), evidence suggests that the arch continued to be positive relative to the Snowcrest and Big Snowy troughs during Lombard facies time. As the Heath and Otter Formation shales thin onto the arch from the Big Snowy trough they grade into the bioclastic limestone of the Lombard facies (Blake, 1959). Similarly, from the central Bridger Range, the Lombard facies thins and grades into a lime bio-grainstone at the Middle Fork of Sixteenmile Creek section on the Lombard arch, suggesting that relatively shallower, agitated conditions existed on the Lombard arch. Thus, deposition continued on the arch but resulted in a thin sedimentary section due to lack of significant subsidence.

South of the central Bridger Range the Lombard facies thins to zero at the Bridger Peak section (Plate 1). Farther south, Lombard facies is not recognized except at Bridger Canyon where three meters of dark gray to black lime mudstone with thin interbeds of black shale overlies the Kibbey Formation. Evidence of shoaling conditions as seen on the Lombard arch is absent here. How far the Lombard facies extended south of Bridger Canyon and how thick it was is conjectural since evidence was removed by pre-Amsden erosion.

Upper Big Snowy Group Contact and the Amsden Formation

Description. The contact between the Big Snowy Group and the Amsden Formation is easily located where Lombard facies limestone is present. At such localities red mudstone and siltstone of the Amsden Formation overlie an irregular calcite-dolomite-quartz duracrust (caliche) up to one meter thick on the Lombard facies. At locations where the Amsden Formation overlies the Kibbey Formation the contact is less easily discerned because of similarity in lithologies. In the Bridger Range, this contact is placed above the tabular upper Kibbey sandstone or below the lower Amsden red mudstone-siltstone interval. Differences in bed lithology and geometry of the Kibbey and Amsden Formations are the most reliable indicators at these locations.

The lower Amsden Formation consists of red mudstone and siltstone with lenses and beds of variably colored sandstone, lime bio-wackestone and packstone and fine grained massive dolostone. Conodont dates establish an early Morrowan age for the Amsden Formation just above the Big Snowy Group contact (Plate 1; Appendix) (written communication, Wardlaw, 1983). The sampled interval varies from thirty-two meters on the south at Rocky Canyon, to fifty-seven meters at South Angler, to zero at Middle Fork Sixteenmile canyon on the north end of the study area.

Interpretation. Direct and indirect lithologic and stratigraphic evidence indicates an unconformity is present between the Big Snowy Group and Amsden Formation in the Bridger Range. The duracrust developed along the contact where the Lombard facies overlies the Amsden Formation indicates a period of exposure to weathering. Also, a sharp lithologic change from black limestone to red mudstone and siltstone indicates a sharp change in environments.

The negative tectonic behavior of the central Bridgers during Kibbey and Lombard time also operated during uplift and erosion of the Big Snowy Group before the Amsden transgression. The greatest erosion and therefore relative uplift as evidenced by removal of the entire Lombard facies, occurred where Kibbey sediments are thinnest. Where the Lombard is thickest, the Kibbey is also thick. As previously discussed, the exception to this general pattern is seen between Ross Peak and Bighorn Lake (Plate 1).

IMPLICATIONS: TECTONIC INFLUENCE ON SEDIMENTATION

The late Mississippian paleotectonic framework in the Bridger Range is a local manifestation of the paleotectonic framework of Montana. Regional isopach and facies studies of Proterozoic and Paleozoic rocks in Montana indicate that paleotectonic elements which were influential on late Mississippian sedimentation (Figure 1) were similarly influential prior to and following Big Snowy time. For example, in central Montana the late Mississippian Big Snowy trough coincides closely with the Proterozoic Belt basin and Paleozoic Central Montana trough in which thick sections of Proterozoic and Paleozoic rocks are preserved (Peterson, 1981). In southwest Montana the Snowcrest trough coincides with the Ruby trough (Peterson, 1982) which had a similar long-lived history of relative subsidence.

Geologists studying Proterozoic and Paleozoic rocks on a regional scale conclude that the margins of these paleotectonic elements are coincidental with, and controlled by zones of basement weakness. For example, using stratigraphic and structural evidence, Maughan and Perry (1982) observed that the Snowcrest-Greenhorn line which forms the southeastern margin of the Snowcrest trough follows a zone of basement weakness. The boundary between the Big Snowy trough and Wyoming shelf is similarly believed to be located on an east-west zone of basement weakness (Maughan, 1984).

The Bridger Range lies near where these two structural

lineaments meet. Proterozoic and Paleozoic rocks have a maximum thickness somewhere north of Ross Pass in the unstable trough and thin onto the Wyoming shelf south of Ross Pass.

Ross Pass has had an important and long-lived structural history. The pass area was the southern boundary of the Proterozoic Belt basin. A thick, extremely coarse conglomerate facies of the Belt abuts against Archean rocks at Ross Pass. As McMannis (1963) pointed out, these relationships strongly suggest a Proterozoic fault bounding the southern Belt basin.

The southern faulted margin of the Proterozoic Belt basin coincides roughly with the boundary between the Paleozoic Wyoming stable province and Central Montana unstable province. Thus, in the Bridger Ranger we have direct evidence of coincidence between a Proterozoic zone of weakness and differential movements on paleotectonic elements during the Paleozoic.

CONCLUSION

The Big Snowy Group disconformably overlies the Mission Canyon Formation in the Bridger Range. The contact is characterized by a change from clean, oolitic, Mission Canyon lime bio-wackestone to muddy, silty, laminated dolostone. The rocks are not gradational and do not interfinger across the contact indicating that a single, extensive surface of disconformity developed. Sando (1976) recognizes that there are three, and possibly four, faunal zones missing across the contact.

The lower member of the Kibbey Formation represents a sabkha deposited at the leading edge of the Big Snowy sea as it transgressed northeastward into the Bridger Range. Algal laminae, dessication features, and fenestral fabric are common in the lower Kibbey Formation dolostone. Lucia (1972) attributes such structures primarily to intermittently flooded supratidal and high intertidal marginal marine zones. Dolostone breccias in the lower Kibbey Formation are interpreted as evaporite solution zones. This indicates that a hot, arid climate prevailed at this time. Intertidal siliciclastic channels (creeks) migrated across the sabkha in the central range area. The lower Kibbey channels are similar to modern channels on Andros Island as described by Shinn, Lloyd, and Ginsburg (1969). Both fine up from sandstone or conglomerate on a sharp contact cut into underlying sediments into siltstone, and

mudstone. Tidal channels are restricted to the low lying, intertidal areas on modern sabkhas.

The upper member of the Kibbey Formation is a primarily regressive offshore to shoreface deposit. Mudstones at the base were deposited by suspension in a lower shoreface setting. Interlayered and graded siltstone and sandstone within the mudstone were deposited by intermittent storm currents, possibly combined with tidal currents. Increasing grain size and decreasing mud content upsection in the shoreface deposit reflect higher energy conditions associated with the strandline as the regression continued. High angle tangential and trough cross beds near the top of the upper member is similar to middle and upper shoreface cross bedding reported in modern sediments (Campbell, 1971; Howard, 1971; Reinech and Singh, 1973). Lagoonal and tidal flat siltstone, mudstone, and dolostone at the top of the Kibbey Formation indicate that regression continued until intertidal, and possibly supratidal, conditions returned to the Bridger Range area.

Several hypotheses may be proposed to explain the upper Kibbey regressional episode. A period of relative sea level lowering, caused either by tectonic uplift or regional sea level fall, could cause a regression of the shoreface facies. Also, increased sediment supply to the area could produce outward building or regression of the shoreface, particularly during a period of relative sea level stability. Regional analysis is needed to determine which mechanism is primarily responsible.

The Big Snowy sea returned again but left scant record in the

Kibbey Formation. Transgressive shoreface deposits such as upward coarsening sandstones are not recognized in the upper member. However, thin lithoclast conglomerates are preserved at several sections on the upper and lower contact of the upper member. These conglomerates represent minor disconformities generated during transgression by shoreface erosion. Clifton (1973) reported a similar situation in modern deposits. Where the conglomerate is missing in the Bridger Range, a minor transgressive sequence may be present.

The Lombard facies overlying the Upper member of the Kibbey Formation was deposited in a shelf lagoon (as defined by Wilson, 1975). The Lombard facies is composed primarily of dark colored lime mudstone and shale deposited by suspension. Circulation in the Lombard lagoon was restricted by a topographic barrier on the shelf margin near the extreme southwest part of the Snowcrest trough (Rose, 1976), or by the geometry of the lagoon itself as proposed for modern epicontinental seas (Logan and Cebulski, 1970). Intermittent storm currents, possibly combined with tidal currents, brought small amounts of crinoid and shell debris into the Bridger Range area and deposited them as packstone and wackestone.

Sediments at the base of the Lombard facies were bioturbated in relatively normally oxygenated water. The loss of evidence of benthic fauna upsection suggests that the environment became restricted and somewhat anoxic, at least near the bottom of the lagoon. Pelagic foraminifera wackestone at the top of the Lombard facies, however, indicates that surface waters were oxygenated enough

to support surface fauna during late Lombard time. Thus, the upper Lombard facies was deposited under a stratified water column in much the same way as reported for other Paleozoic lagoonal deposits (Potter, Maynard, and Pryor, 1982).

A regional unconformity is developed at the top of the Lombard facies (Sando, 1976; Maughan, 1984). In the Bridger Range, a duracrust marks the contact. A sharp lithologic change at most exposures is evidence of change in depositional environments across the unconformity.

The central Bridger Range subsided relative to the Wyoming shelf and Lombard arch during Big Snowy deposition. Environments of the lower and upper members of the Kibbey Formation and the Lombard facies indicate that deeper water conditions persisted in the central range area due to this subsidence. Also, significantly thicker stratigraphic sections are preserved here. The exception to this general pattern between Ross Peak and Bighorn Lake was caused by a local positive element within the central part of the range.

The negative tectonic tendency of the central Bridger Range was also influential during uplift and erosion of the Big Snowy Group prior to the Amsden transgression. Greatest erosion and therefore relative uplift is indicated by removal of the entire Lombard facies, and in some cases, thinning of the upper member of the Kibbey Formation. This occurred where the entire Kibbey Formation is thinnest. Where the Lombard is thickest, the Kibbey is also thick. The end result is that elements which were positive during deposition remained positive during pre-Amsden erosion, and thin deposits of the

Big Snowy Group on these elements were thinned more. Inversely, thicker deposits on negative elements were preserved from erosion and remained thick. In this way both depositional thinning and post-depositional erosion are responsible for thickness trends of the Big Snowy Group in the Bridger Range.

The central Bridger Range is an ancient zone of crustal weakness. During the Proterozoic, the Dillon block south of the central Bridger Range was uplifted along a fault through Ross Pass forming the southern margin of the Belt basin (McMannis, 1963). Similarly during the Paleozoic, the Wyoming shelf south of the central Bridger Range was stable, or neutral, relative to the unstable trough to the north (Peterson, 1981). These tectonic controls resulted in thick stratigraphic sections of Proterozoic and Paleozoic rocks north of the central range area, and thin or missing sections to the south. During late Mississippian, the central Bridger Range acted as an unstable trough between the Wyoming shelf and Lombard arch. Big Snowy rocks are thin or missing on the Wyoming shelf and Lombard arch, and are thicker in the central range area. These relationships provide insight into the nature of tectonic influence that the zone of crustal weakness in the Bridger Range had on sedimentation of Proterozoic and Paleozoic rocks. Big Snowy Group lithofacies and stratigraphy provide particularly good evidence of this influence. Undoubtedly, future studies here will provide more evidence of the influence this ancient zone of weakness had on sedimentation of other rocks. Such studies might further elucidate the distribution of paleotectonic movements in time and space.

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APPENDIX

Descriptions of measured sections
 Conodonts interpreted by Bruce Wardlaw,
 United States Geological Survey

ROCKY CANYON SECTION

(High on wall of rocky canyon north of interstate,

Unit thickness Sec. 19, T. 2 S., R. 6 E.)

in feet

Amsden Formation (part):

- 48'.....Covered-brown soil.
- 22'.....Siltstone-purple-red, sandy at base, covered in middle.
- 8'.....Sandstone-pink and maroon, minor siltstone.
- 16'.....Siltstone-brown-red, partly covered.
- 10'.....Dolostone-lavender mottled cream, thin to thick bedded,
 minor red siltstone.
- 12'.....Dolostone-white, dense, massive, weathers to rounded
 knolls, (tectonic?) breccia, crude laminations.
- 4'.....Covered.

Upper Member Kibbey Formation:

- 10'.....Sandstone-generally as below, with siltstone.
- 10'.....Sandstone-white and lavender, fine grained, moderately
 sorted, poorly preserved, tangential trough cross bedded, 15
 degree maximum dip.
- 16'.....Sandstone-brick red and pale green, minor white and pink,
 fine to medium grained, moderate and poor sorting, partly
 covered.
- 10'.....Conglomerate-brick red sandstone matrix, fine to medium

grained, with dolostone and sandstone lithoclasts up to 1/4 inch supported by matrix, sub-rounded, partly covered.

4'.....Siltstone-brick red, lower red mudstone.

Lower Member Kibbey Formation:

6'.....Dolostone-lavender mottled green, as below with a thin red mudstone.

16'.....Dolostone-purple-maroon, minor green, dense, massive, wavy laminations, basal yellow and muddy.

8'.....Dolostone breccia-pink, orange, yellow, gray, purple and maroon at top, clasts up to 3 feet.

80'..Total Big Snowy Group

Mission Canyon Formation (part):

Limestone and Dolostone-light gray to tan, very coarsely crystalline, tectonically brecciated.

BRIDGER CANYON SECTION
(3/4 mile north of road through canyon,
Sec. 27, T. 1 S., R. 6 E.)

Amsden Formation (part):

7'.....Dolostone-yellow-green, fractured.

7'.....Covered-reddish soil, minor red and green mudstone cropping out.

Lombard Facies:

8'.....Limestone-dark gray, dense, finely crystalline, medium bedding, black mudstone interbedded, calcite filled fractures.

Upper Member Kibbey Formation:

16'.....Sandstone-white, maroon-purple, fine grained generally massive with thin muddy interbeds, becomes siltstone at top.

Lower Member Kibbey Formation:

9'.....Siltstone and Dolostone-maroon mottled green and white.

3'.....Siltstone-brick red.

12'.....Siltstone-maroon mottled yellow-cream, brecciated, minor fine grained sandstone, basal part filling Karst-sink in Mission Canyon Formation.

48'..Total Big Snowy Formation

Mission Canyon Formation (part):

Limestone-medium brown-gray, finely crystalline, few corals, Lower Kibbey sediments filling Karst-sink.

BRIDGER PEAK SECTION

(Just northwest of Saddle Peak, NW 1/4 Sec. 36, T. 1 N., R 6 E.)

(Measurements and some descriptions from McMannis, 1951.)

Amsden Formation (part):

18'.....Dolostone-purple, mottled pale green, massive.

7'.....Siltstone-brick red, mottled, with interbedded red mudstone, purple dolostone at top, partially covered.

Upper Member Kibbey Formation:

23'.....Sandstone-red at top and bottom, white in middle, fine grained, medium grain in middle, faint cross bedding.

10'.....Siltstone-brick orange, purple, muddy.

Lower Member Kibbey Formation:

35'.....Dolostone-various pastel colors, predominantly maroon mottled green, silty, laminated in part, few breccia zones.

14'.....Dolostone-purple and cream mottled, massive, laminated, muddy, few breccias.

6'.....Siltstone-purple and red mottled, brecciated.

14'.....Dolostone-cream and purple mottled, brecciated.

102'..Total Big Snowy Group

Mission Canyon Formation (part):

Limestone-medium gray-brown, massive, few fossils.

MAYNARD CREEK SECTION
(Bridger Bowl ski area, SW 1/4 Sec. 24, T. 1 N., R 6 E.)

Amsden Formation (part):

- 1'.....Clay-red.
- 4'.....Dolostone-buff-pink, granular, slightly sandy.
- 8'.....Dolostone-red and maroon mottled, possibly bioturbated.
- 4'.....Mudstone/claystone-red-brown.
- 12'.....Covered-probable red mudstone and siltstone.
- 6'.....Dolostone-very light gray-lavender, finely crystalline, smooth concave weathered surfaces, massive.
- 2'.....Quartz-calcite duracrust-yellow, basal red mudstone-claystone.

Lombard Facies:

- 6'.....Limestone-medium to light gray, medium crystalline, fossiliferous, top is pink mottled.
- 4'.....Limestone-as above, well developed medium bedding, few bio-wackestone beds, cherty.
- 18'.....Limestone-olive dolomitic as above, solitary corals a top, Chesterian CONODONTS from top.
- 4'.....Dolostone-purple and pink-red, yellow weathering.
- 12'.....Limestone-as above, with silty-muddy partings.
- 18'.....Limestone-dark gray-black, bottom 2/3 is muddy, silty, thin bedded to fissile, solitary corals at base, Chesterian CONODONTS from top.
- 8'.....Limestone-as above with mudstone-green and gray, Chesterian CONODONTS from top.
- 2'.....Sandstone-green and gray.

Upper Member Kibbey Formation:

- 4'.....Dolostone-lavender, silty, muddy.
- 4'.....Sandstone-pink and green, very fine, fine, and medium grained, moderate to poor sorting, tabular outcrop, minor mudstone.

Lower Member Kibbey Formation:

- 8'.....Dolostone-pale orange to pink, bottom 2/3 brecciated, basal green and purple mudstone.
- 10'.....Dolostone-orange-red, with sandstone, siltstone and mudstone.
- 20'.....Dolostone-pink-red and pale green-yellow, mottled maroon, silty, minor breccia.

Total Big Snowy Group

Mission Canyon Formation:

Limestone-medium gray, finely crystalline, massive.

ROSS PEAK SECTION

(NE slope of peak, SW 1/4 Sec. 2, T. 1 N., R. 6 E.)

Amsden Formation (part):

- 1'.....Dolostone-light gray, finely crystalline.
- 50'.....Covered-red soil and debris.

Lombard Facies:

- 32'.....Limestone-cream-pink, olive, and brown, medium and thin bedded fossiliferous, one solitary coral collected from top, possible sponge from top, brown chert nodules, lenses, and fragments, late Chesterian CONODONTS 18 feet from top.
- 12'.....Limestone-medium brown-red, medium crystalline, thin to platy bedding, bio-wackestone and packstone beds abundant, minor orange limestone.
- 16'.....Limestone-black, thin to platy bedded, fossiliferous, abundant black mudstone interbeds, Chesterian CONODONTS from base.
- 16'.....Limestone-medium gray-black, finely crystalline, very fossiliferous, massive.

- 6'.....Shale-black, silty, limy.
- 14'..... Covered-brown soil, grassy.
- 6'..... Limestone-medium brown-gray, as below, possible intraclast conglomerate.
- 20'..... Covered-dark brown soil, grassy.
- 6'..... Limestone-upper medium brown-gray, lower lavender, finely crystalline, sandy, 1/2 inch horizontal worm tubes.
- 12'.....Covered-dark brown soil, grassy.
- 6'.....Limestone-medium gray-brown, medium and coarsley crystalline, fossiliferous, middle 2 feet is black micritic, muddy limestone, Chesterian CONODONTS from base and top.
- 14'.....Covered-dark brown soil, grassy.

Upper Member Kibbey Formation:

- 4'.....Conglomerate-maroon, subrounded sandstone and dolostone clasts in siltstone matrix.
- 2'.....Mudstone-red.
- 6'.....Sandstone-dark red-maroon, very fine grained, dark red mudstone chips in middle.
- 14'.....Sandstone-white, very fine grained, well sorted, well indurated, massive.
- 10'.....Sandstone-as above, fine grained.
- 2'.....Mudstone-brick red, lavender.
- 26'.....Sandstone-pale yellow-orange, fine to medium grained, moderately well sorted, 10 inch deep trough cross beds.
- 8'.....Sandstone-brick red, very fine grained, calcareous.

Lower Memeber Kibbey Formation:

- 30'.....Siltstone-brick red, mottled yellow, fine wavy laminations, dolomitic, interbedded with sandstone brick red, very fine grained, dolomitic, and dolostone, maroon, lavender.
- 16'.....Dolostone-various pastel colors predominantly maroon

silty, muddy, thin wavy laminations, with interbedded siltstone as above.

14'.....Siltstone-predominantly brick red and gray red, mottled yellow, blocky fracture, few very fine sandstones as above.

8'.....Dolostone-as dolostone above.

19'.....Dolostone-yellow-gray mottled lavender, thin bedded, three fining upward sequences of pink-maroon sandstone, siltstone, mudstone, sharp basal contact.

1'.....Lithoclast Conglomerate-maroon, discontinuous, sandstone and siltstone clasts.

336'..Total Big Snowy Group

Mission Canyon Formation (part):

Limestone-medium gray, massive, contact with Kibbey has 3 feet of relief, lithoclast conglomerate fills low areas.

STATION 191 SECTION

(One mile north of Ross Peak, SW 1/4 Sec. 35, T. 2 N., R. 6 E.)

Amsden Formation (part):

10'.....Covered-orange-pink, soil.

4'.....Limestone-very light gray. bio-wackestone.

14'.....Dolostone-purple and green mottled.
Limestone-medium gray, dense, bio-wackestone, and packstone.

9'.....Predominantly covered-brown soil with red siltstone and sandstone cropping out at top, red soil with red-orange silty mudstone at base.

Upper Member Kibbey Formation:

34'.....Sandstone-yellow at bottom, white in middle, red at top, fine and medium grained, moderately well sorted, planar laminations, poorly preserved low-angle cross beds.

1'.....Conglomerate-yellow, subrounded limestone clasts in muddy sandstone.

6'.....Dolostone-red, sandy.

- 4'.....Siltstone-red.
- 4'.....Dolostone-red, silty.
- 4'.....Siltstone-red, basal red mudstone.
- 6'.....Dolostone-pink, green and purple mottled, smooth concave weathered surfaces.

Lower Member Kibbey Formation:

- 12'.....Conglomerate-purple and pale green dolostone with dolostone and sandstone clasts, red, purple, and pale green, sub-rounded.
- 71'..Total Big Snowy Group

Mission Canyon Formation (part):

- 6'.....Limestone Breccia-pink, 1 inch clasts.

SOUTHEAST SACAJAWEA SECTION
(One mile south of Fairy Lake,
NE 1/4 Sec. 27, T. 2 N., R 6 E.)

Amsden formation (part):

- 22'.....Mudstone-brown-red, thinly bedded with 3 limestone beds, yellow-gray, red, finely crystalline, massive.
- 18'.....Limestone-pale, red-purple, mottled gray, finely crystalline, very fossiliferous.
- 14'.....Covered-brown-red, sandy, mudstone debris.
- 6'.....Limestone-white-pale gray-red, medium to fine grained, massive, fossiliferous, early Morrow CONODONTS from base.

Upper Member Kibbey Formation:

- 24'.....Sandstone-brown-red and pink, fine grained, muddy, thin bedded.
- 14'.....Sandstone-as sandstone below.
- 4'.....Mudstone-brown-red, sandy.

- 40'..... Sandstone-pale green, white and pink mottled, spotted orange in part, medium grained at top, fine grained at base, partial cover towards bottom.
- 16'..... Siltstone-pale green and pale red, dolomitic, sandy.
- 4'..... Sandstone-brick red, fine grained.
- 2'..... Siltstone-brick red.
- 2'..... Mudstone-brick red.
- 8'..... Sandstone-red orange mottled pale orange, dolomitic, fine grained, medium to thick irregular beds.
- 6'..... Siltstone-red-brown and brick red, gradational from mud below to sandstone above.
- 4'..... Mudstone-brick red.
- 2'..... Breccial Conglomerate-brick red.
- Lower Member Kibbey Formation:
- 22'..... Sandstone and Siltstone-purple-red, mottled green in part, at least 4 upward fining lenses.
- 2'..... Mudstone-red.
- 8'..... Dolostone-brick red, sandy, silty, with minor sandstone and siltstone beds.
- 18'..... Dolostone-tan, minor pink and purple, predominantly covered with red soil, wavy laminations.
- 176'.. Total Big Snowy Group

Mission Canyon Formation (part):

Limestone-medium gray-brown, massive.

EAST SACAJAWEA SECTION
 (Measurements and some descriptions
 from McMannis, 1951.)
 (On ridge just SW of Fairy Lake,
 NE 1/4 Sec. 27, T. 2 N., R 6 E.)

- 18'..... Siltstone-brick red and purple.

- 14'..... Limestone-purple, mottled gray, fossiliferous, few interbeds of brick red silty mudstone.
- 30'..... Siltstone-brick red and purple, few mudstone and sandstone interbeds, mostly covered.
- 8'..... Limestone-purple, mottled gray, massive, fossiliferous.

Upper Member Kibbey Formation:

- 58'..... Sandstone-white-cream, fine grained at base and top, medium grained in middle, poorly preserved cross beds, interbedded siltstone.
- 8'..... Mudstone-purple, predominantly covered.
- 36'..... Siltstone-red, predominantly covered.

Lower Member Kibbey Formation:

- 20'..... Dolostone-pink-gray, mottled green, silty, breccia at base.
- 60'..... Dolostone-various pastel colors, predominantly yellow and pink, silty, wavy laminations, breccia zones.
- 182'..Total Big Snowy Group

Mission Canyon Formation (part):

Limestone-medium gray, massive, fossiliferous.

BIGHORN LAKE SECTION

(On ridge just south of Bighorn Lake,
SW 1/4 Sec. 15, T. 2 N., R. 6 E.)

Amsden Formation (part):

- 48'..... Siltstone-red, purple, dolomitic, with interbedded limestone as below, brick red silty mudstone, and silty, purple, dolostone.
- 8'..... Limestone-purple, silty, massive, fossiliferous.
- 34'..... Covered-red-pink soil with purple limestone debris.

Lombard Facies:

- 20'..... Limestone-light gray, coarsley crystalline, medium and thick bedded, cherty, fossiliferous, few solitary corals at

top.

- 30'..... Limestone-medium gray, light gray at base, thin and medium bedded as above.
- 10'..... Limestone-medium and dark gray, silty, fossiliferous, beds of bio-packstone, late Chesterian CONODONTS from base.
- 4'..... Covered-pink soil.
- 2'..... Limestone-purple, pink mottled, and yellow-tan, dolomitic, very fine crystalline.

Upper Member Kibbey Formation:

- 6'..... Siltstone-purple, 2 foot mudstone at base.
- 16'..... Sandstone-pale orange-red and pink, dolomitic, few thin beds of dolostone, fine grained, well sorted, medium bedded.
- 2'..... Mudstone-red.
- 8'..... Sandstone-white-very pale green, clean, massive.
- 8'..... Sandstone-as below grading up into rippled laminations, partings 2 inches apart.
- 10'..... Sandstone-white, red chert grains visible, fine grained, calcareous, 1 inch high ripples on 5 inch high trough cross beds.
- 6'..... Mudstone-purple, cream mottled, dolomitic siltstone at top.
- 4'..... Sandstone-pink-yellow, medium grained, moderate sorting, clean, 4 inch beds with planar laminations.
- 8'..... Siltstone-purple, cream mottled, dolomitic, silty dolostone in part, purple mudstone at base.
- 8'..... Sandstone-purple, gray, and tan, medium grained, moderately sorted, 3 foot massive lens at top with trough cross beds.
- 4'..... Mudstone-dark red, minor purple.
- 8'..... Sandstone-purple mottled green, very fine grained, massive, dolomitic.

Lower Member Kibbey Formation:

- 24'..... Sandstone-siltstone and mudstone-red and brick red,

upward fining lenses, lithoclast conglomerate at base on sharp lower contact, few pale pastel dolostone beds.

10'.....Dolostone-upper purple, lower cream-buff mottled red and pink, smooth, concave weathered surfaces, thin irregular laminations at base.

10'.....Covered-pink-brown soil.

198'..Total Big Snowy Group.

Mission Canyon Formation (part):

4'.....Limestone-light gray, mottled yellow, medium to finely crystalline, somewhat fossiliferous.

8'.....Covered-brown soil.

40'.....Limestone-medium gray, basal yellow-tan to gray, generally as above, 12 feet breccia in middle, lower pink silty limestone.

NORTHWEST BIGHORN LAKE SECTION
(On ridge just NW of Bighorn Lake,
NW 1/4 Sec. 10, T. 2 N., R. 6 E.)

Amsden Formation (part):

14'.....Sandstone-light gray-white, very fine grained, thin bedded, calcareous, silty at base.

28'.....Limestone-dark gray, lavender, nodular weathering, with interbedded siltstone, purple, pink, muddy, partly covered.
Covered-orange-red soil.

8'.....Limestone Breccia-gray.

12'.....Covered-orange-red soil.

30'.....Limestone-gray, lavender, dolomitic.
Covered-pink soil at top, red soil at base.

Lombard Facies:

36'.....Limestone-dark gray, minor pink-yellow, fossiliferous, solitary corals in middle, cherty.

16'.....Limestone-as above, very fossiliferous

Upper Member Kibbey Formation:

- 14'..... Siltstone-as below, with interbedded sandstone and dolostone.
- 10'..... Sandstone-purple and green mottled, very fine grained, medium bedded, silty.
- 4'..... Mudstone-orange, grading up into sandstone, red.
- 10'..... Sandstone-pink at base, white at top, medium and fine grained thin bedded dolomitic.

NOTE: Fold or fault in section, measurements below are questionable.

- 26'..... Sandstone-dolomitic, minor siltstone, faint cross beds.

Lower Member Kibbey Formation:

- 50'..... Siltstone-maroon-red and orange, dolomitic, with interbedded dolostone and sandstone.
- 38'..... Covered-brick red siltstone debris.
Total Big Snowy Group

Mission Canyon Formation (part):

- 6'..... Limestone Breccia-maroon, silty.
- 4'..... Covered.
- 6'..... Limestone-very dark gray, massive.
- 14'..... Covered.
- 14'..... Dolostone-olive, gray, granular.
- 30'..... Covered-partial exposures of silty gray-lavender limestone.

SOUTH ANGLER SECTION
(On ridge just south of Angler Lake,
Sec. 15, T. 2 N., R. 6 E.)

Amsden Formation (part):

- 50'..... Covered-maroon siltstone debris, grassy.

65'.....Covered-dark brown soil, red in part, grassy.

Lombard Facies:

30'.....Limestone-dark and medium gray, brown-orange in part, fine to medium crystalline, thick and medium bedded, sparse fossils, solitary corals in top 9 feet.

22'.....Limestone-dark gray, gray-brown at top, finely crystalline dense, massive, fossiliferous, wackestone and packstone interbeds, cherty.

12'.....Limestone-medium and dark gray, yellow-gray weathering, massive with few silty, muddy beds, fossiliferous, basal bio-wackestone and packstone bed.

8'.....Mudstone-black and gray, red at base, silty, partly covered.

Upper Member Kibbey Formation:

44'.....Dolostone-upper lavender, middle pink mottled pale green, lower brick red, silty at base, thinly laminated in part.

4'.....Siltstone- red-purple, muddy.

24'.....Dolostone-various pastel colors, predominately orange-yellow, brick red at base, silty at base, thin laminations, irregular lumpy bedding.

14'.....Siltstone-brick red, dolomitic, with silty dolostone.

46'.....Sandstone-red, minor orange, yellow, pink, fine grained, interbedded brick red siltstone.

10'.....Siltstone-brick red and purple, sandy, with silty sandstone.

40'.....Sandstone-brick red, fine and very fine grained, silty at base.

Lower Member Kibbey Formation:

10'.....Mudstone-brick red, silty, with siltstone, mostly covered.

10'.....Sandstone-yellow, pink, minor red-orange, fine and medium grained, moderate sorting, dolomitic muddy siltstone in middle.

- 30'.....Siltstone-red, yellow-brown at base, dolomitic, few breccia zones, 5 sandy units.
- 10'.....Siltstone-yellow-brown, as above.
- 36'.....Dolostone-maroon, pink, tan, minor purple mottled green, laminated, silty, muddy, few thin siltstone beds.
- 4'.....Siltstone-maroon, dolomitic, 6 feet of relief on Mission Canyon contact, lithoclast conglomerate in low areas.
- 358'..Total Big Snowy Group

Mission Canyon Formation (part):

Limestone-medium gray-brown, massive and thick bedded, brecciated in part.

NORTH ANGLER SECTION

(On ridge just north of Angler Lake,
SW 1/4 Sec. 10, T. 2 N., R. 6 E.)

Amsden Formation (part):

- 26'.....Siltstone-purple, maroon, brick red, very fine sandstone in part, partially covered.
- 10'.....Limestone-pale brown-gray, thin lumpy bedding, fossiliferous, cherty.
- 18'.....Limestone-medium gray-lavender, fossiliferous, with interbedded purple-red silty mudstone, partly covered.
- 6'.....Limestone-yellow-gray, sandy.
- 3'.....Calcite Duracrust.

Lombard Facies:

- 4'.....Limestone-as limestone below.
- 6'.....Dolostone-pale purple-gray, limestone in part, partly covered.
- 24'.....Limestone-pale gray, brown, lavender, well developed thin

and medium bedding, fossiliferous, cherty.

- 16'.....Limestone-as above, silty and thick bedded at base.
- 10'..... Limestone-lavender, finely crystalline, medium and thick bedding, cherty, thin silty shale interbeds.
- 6'.....Limestone-gray, yellow weathering, silty, very fossiliferous, thin bedded, late Chesterian CONODONTS from middle.
- 3'.....Limestone-gray, thick bedded.
- 4'.....Limestone-medium brown-gray, irregular and platy bedding, fossiliferous.
- 3'.....Limestone-gray, thick bedded.
- 8'.....Covered-brown soil.

Upper Member Kibbey Formation:

- 8'.....Dolostone-light yellow and pale maroon, laterally discontinuous, wavy laminations, silty, sandy.
- 6'.....Covered- pink-orange soil.
- 30'.....Siltstone-brick red, purple, pink, orange, with interbedded mudstone and sandstone.
- 20'.....Sandstone-yellow-orange, pink, fine grained, thin to medium bedded, 1 1/2 inch high cross-beds, 15 degree maximum dip.
- 9'.....Sandstone-lower red, upper white, lens 150 feet wide, medium grained, 25 degrees south dipping cross strata at base, planar laminated at top, lens enclosed by similar fine grained sandstone.
- 28'.....Sandstone-brick red, massive, fine grained, trough cross-beds with ripple cross strata.
- 14'.....Siltstone-brick red, muddy at base, sandy at top, dolomitic.

Lower Member Kibbey Formation:

- 70'.....Dolostone-lavender and maroon, silty, muddy, breccia zones, laminated zones, interbedded siltstone.
- 10'.....Dolostone-gray, yellow weathering, laminated, basal 4 inches burrowed.
- 279'..Total Big Snowy Group

Mission Canyon Formation (part):

Limestone-medium gray-brown, weathers gray, coarsely crystalline, fossil fragments.

HORSE MOUNTAIN SECTION

(SW 1/4 Sec. 18 and NW 1/4 Sec. 19, T. 3 N., R. 6 E.)

Amsden Formation (part):

- 50'.....Dolostone-pink-red, variable bedding.
- 30'.....Limestone-pink and purple, granular at top, dense at base, sandy, silty, early Morrow CONODONTS from top.
- 4'.....Limestone-lavender, mottled pale green, fossiliferous, early Morrow CONODONTS from base.

Upper Member Kibbey Formation:

- 30'.....Sandstone-purple with intense green laminations, fine and medium grained, thick bedded, red mudstone interbedded, cross-bedded at base.
- 12'.....Sandstone-red-purple, yellow and white at top, fine and very fine grained, thin bedded, flaggy at base.
- 24'.....Covered-red soil.
- 22'.....Covered-brown soil.

Lower Member Kibbey Formation:

- 4'.....Dolostone-brick red, silty.
- 20'.....Covered-dark brown soil.
- 4'.....Mudstone-red, brecciated.
- 14'.....Breccia-yellow, red purple, equal amounts of dolostone, limestone, and sandstone clasts up to 18 inches in diameter.

2'.....Dolostone-red, with minor red sandstone.

132'..Total Big Snowy Group

Mission Canyon Formation (part):

6'.....Limestone- light gray, finely crystalline, medium bedded.

4'.....Dolostone-brown-gray, laterally discontinuous.

3'.....Limestone-red, purple, breccia at top.

Limestone-gray-brown, weathers gray, massive, some fossils.

MIDDLE FORK SIXTEENMILE CREEK SECTION
(On slope just north of road through canyon,
Sec. 11, T. 4 N., R. 6 E.)

Amsden Formation (part):

8'.....Covered-brown soil.

14'.....Sandstone-white-buff, very fine grained, dolomitic,
small, black chert stringer.

Lombard Facies:

3'.....Limestone-pink-orange, medium crystalline, fossiliferous,
bio-packstone, and grainstone, late Chesterian CONODONTS.

3'.....Limestone-olive, dark gray weathering, brachiopod
grainstone at top, crinoid grainstone at base.

2'.....Mudstone-red, yellow in part, white spotted calcite
(replacing evaporite?).

2'.....Limestone-medium gray-olive, brachiopod wackestone, late
Chesterian CONODONTS.

4'.....Mudstone-red, white spotted in part as above.

2'.....Limestone-very sandy, oil stain in vugs.

Upper Member Kibbey Formation:

8'.....Sandstone-white with orange spots, fine and very fine
grained, dolomitic.

2'.....Mudstone-red.

5'.....Sandstone-as sandstone above, partly covered.

- 4'..... Mudstone-red.
- 5'.....Sandstone-maroon, fine grained.
- 5'.....Siltstone-pink and maroon, predominantly covered.
- 4'.....Sandstone-orange mottled pink, dolomitic.
- 12'..... Mudstone-red, minor green.
- 6'..... Sandstone-red, pink, fine grained, red mud chips, current ripples.
- 3'.....Siltstone-red, muddy at base, sandy at top.
- 9'..... Mudstone-red, silty at top, sharp base on sandstone below.
- 8'.....Sandstone-as sandstone above.
- 5'..... Siltstone-red, maroon, mottled green.
- 8'.....Mudstone-green, red, predominantly covered.
- 12'..... Mudstone-maroon.
- 6'..... Mudstone-green.

Lower Member Kibbey Formation:

- 30'..... Covered- mudstone debris-orange-yellow, pink, marron, green.
- 22'.....Mudstone interbedded with siltstone-lavender, minor green.
- 12'..... Dolostone-brown, white weathering, brecciated in part.
- 16'.....Mudstone-tan-pink, breccia in part, minor pink-brown siltstone predominanatly covered.
- 216'.. Total Big Snowy Group

Mission Canyon Formation (part):

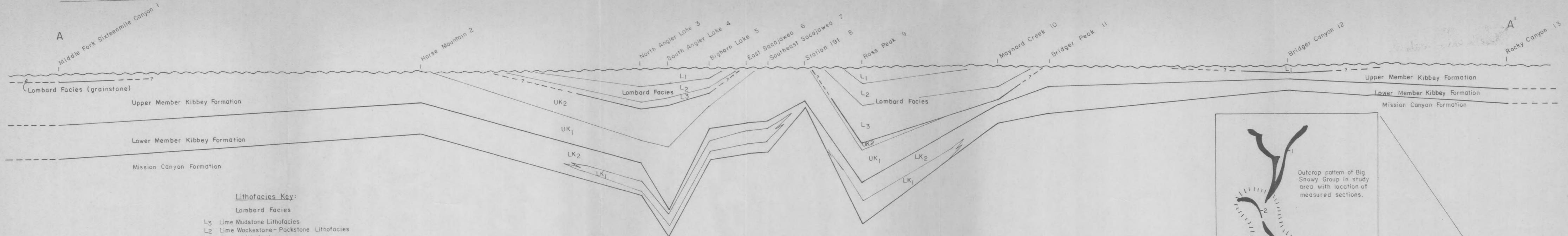
- 12'..... Limestone-pale yellow, dark gray-brown at top, medium bedded, thinly bedded and silty at base.

Limestone-medium gray-brown, massive.

Plate 1

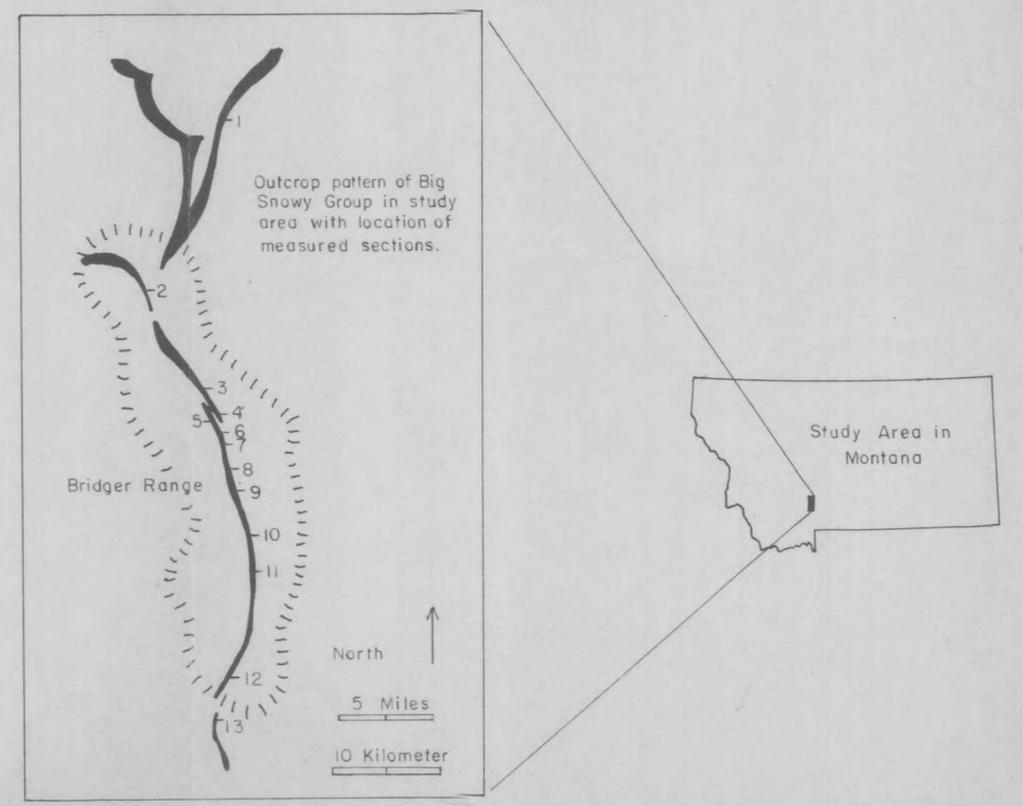
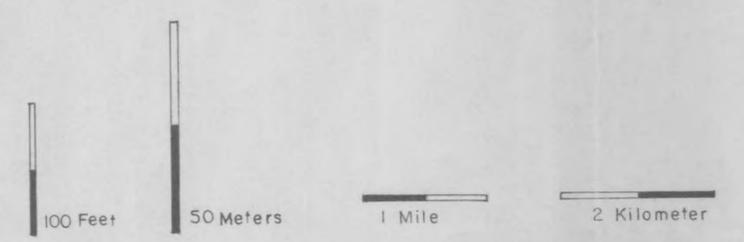
Wyoming Shelf (south)

Lombard Arch (north)



- Lithofacies Key:**
- Lombard Facies**
 L3 Lime Mudstone Lithofacies
 L2 Lime Wackestone-Packstone Lithofacies
 L1 Shale Lithofacies
- Upper Member Kibbey Formation**
 UK₂ Mudstone-Dolostone Lithofacies
 UK₁ Sandstone Lithofacies
- Lower Member Kibbey Formation**
 LK₂ Laminated Dolostone Lithofacies
 LK Sandstone Channel Lithofacies

- Contacts:**
- Formation
 - Lithofacies
 - ~~~~~ Big Snowy-Amsden Unconformity



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