AN ABSTRACT OF THE THESIS OF

Colin F. Key for the degree of Master of Science in Geology presented on May 5, 1986. Title: Stratigraphy and Depositional History of the Amsden and lower Quadrant Formations, Snowcrest Range, Beaverhead and Madison Counties, Montana

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Keith F. Oles

During the Late Mississippian-Early Pennsylvanian (latest Chesterian-early Morrowan), a thick sequence of shallow-water carbonate-clastic sediments, equivalent to the "Amsden" and lower Quadrant Formations, was deposited in the Snowcrest trough on the western margin of the northern Rocky Mountain Cordilleran platform in southwestern Montana. Today this late Chesterian sequence is exposed primarily within the Snowcrest Range which trends in a northeasterly direction through Beaverhead and Madison Counties, Montana.

Conforming to new Late Mississippian nomenclature for rocks in southwestern Montana, the following stratigraphic units, listed in ascending order, were recognized; the Conover Ranch Formation of the Snowcrest Range Group and the Quadrant Formation. In addition, a relatively thick (325 foot average), unnamed, shallow water carbonate sequence was recognized betwwen the Concver Ranch and Quadrant Formations. Thus, three stratigraphic units, the

Conover Ranch Formation, an unnamed limestone unit, and the Quadrant Formation were recognized and comprise the latest Mississippian-earliest Pennsylvanian strata in the thesis area.

The Conover Ranch Formation (late Chesterian) represents a low-energy, marginal marine depositional sequence. The formation consists primarily of red shales and siltstones with occasional quartz arenite-limestone conglomerate lenses. The quartz arenite-limestone conglomerate lenses are thought to represent higher-energy, subtidal channel deposits. The Conover Ranch Formation rests unconformably upon the Lombard Limestone (Big Snowy equivalent) thoughout much of the thesis area.

The unnamed limestone unit (latest Chesterian) was deposited in a shallow-water carbonate shelf environment. The unit consists primarily of wackestones, packstones, and mudstones. Occasionally, an organic-rich mudstone interval was recognized and samples were collected for hydrocarbon source-rock analyses. The unnamed limestone unit grades vertically into a lower dolomitic interval of the Quadrant Formation.

Only the lower dolomitic interval of the Quadrant Formation (latest Chesterian?-Morrowan) was studied in this thesis. The sequence consists primarily of dolostones and dolomite-cemented quartz arenites which were deposited in a littoral to neritic environment. The origin of the dolomite is considered to be secondary, resulting from post-depositional diagenetic events.

In general, the Late Mississippian-Early Pennsylvanian stratigraphic units in the thesis area reflect a single, major transgressive-regressive depositional sequence. The transgression of the sea onto the Cordilleran platform began with the deposition of the Conover Ranch Formation, reached a maximum during deposition of the unnamed limestone unit, and began to retreat off the platform at the onset of clastic deposition characteriztic of the Quadrant Formation.

The overall hydrocarbon source rock potential of the unnamed limestone unit ("Amsden") in southwestern Montana is poor.

Stratigraphy and Depositional History of the Amsden and lower Quadrant Formations, Snowcrest Range, Beaverhead and Madison Counties, Montana.

by

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INTRODUCTION

Through much of the late Paleozoic, sedimentation in Montana was characterized by shallow-water carbonate and clastic deposits on the broad northern Rocky Mountain Cordilleran platform. This platform was bounded to the north by the Canadian shield and to the east by the Transcontinental arch (figure 1). Both of these regions were emergent features during most of the late Paleozoic and consequently provided the bulk of sediments for clastic deposition on the platform. The southern margin of the platform across Montana varied in response to epeirogenic movements along the present day Montana-Wyoming border. To the west, the platform was bounded by the north-south-trending Cordilleran miogeosyncline. The platform to miogeosyncline transition coincides approximately with the Wasatch Line of Kay (1951) and the hinge zone of the western North American craton of Scholten (1957).

During Late Mississippian (Meramecian) to Early Pennsylvanian (Morrowan-Atokan) time, the platform across Montana became tectonically unstable. As a result, an east-west-trending shallow marine trough developed from the southwestern corner of Montana to the Dakotas in the east (figure 2). Although the trough was essentially continuous across Montana, local positive elements divided it into three major depositional entities. From east to west, these are; first, the Williston basin; second, the Big Snowy trough; and third, the Snowcrest trough. During the Late Missis-

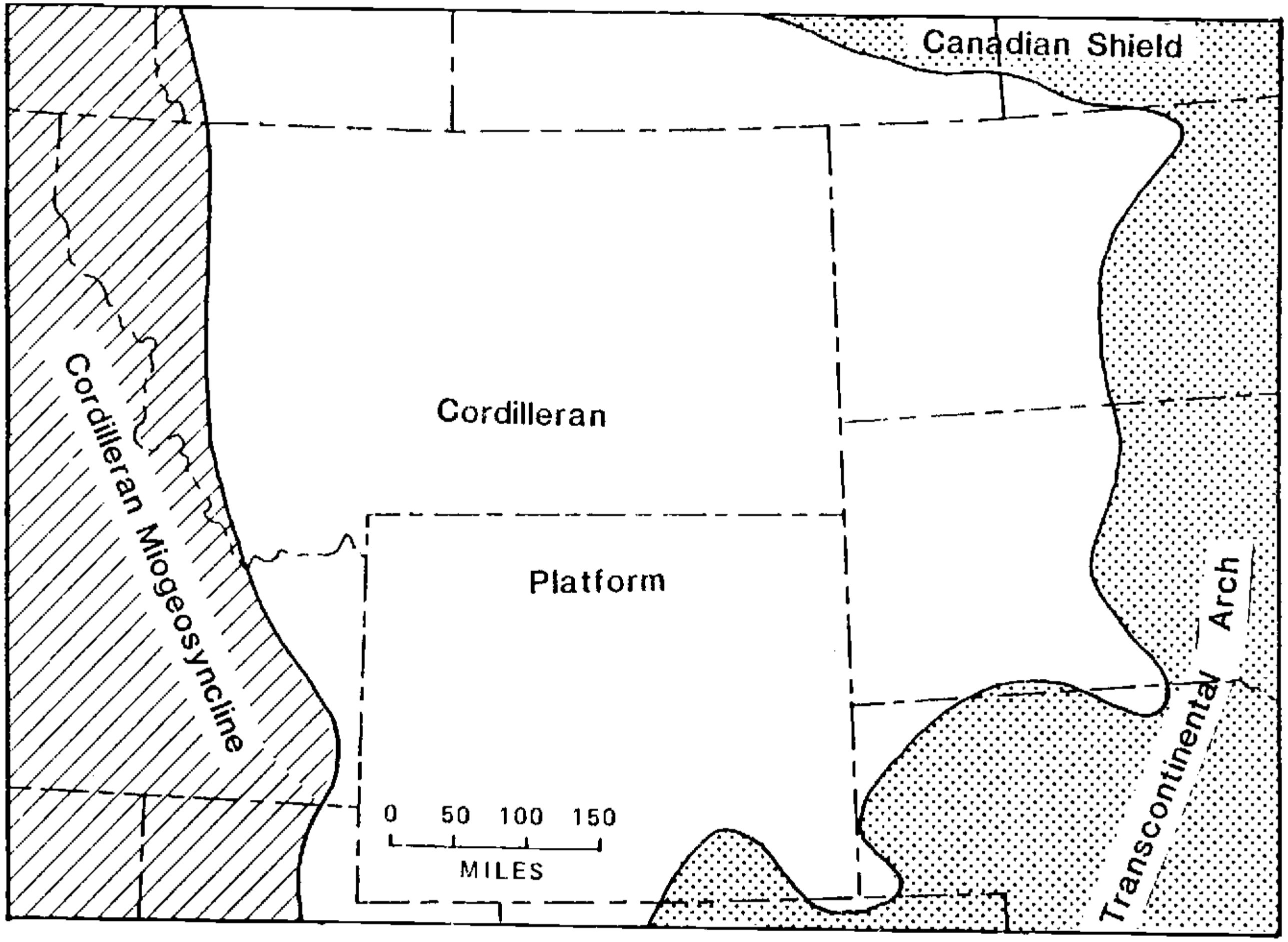


Figure 1. Generalized paleogeography of the northern Rocky Mountain region during the late Paleozoic.

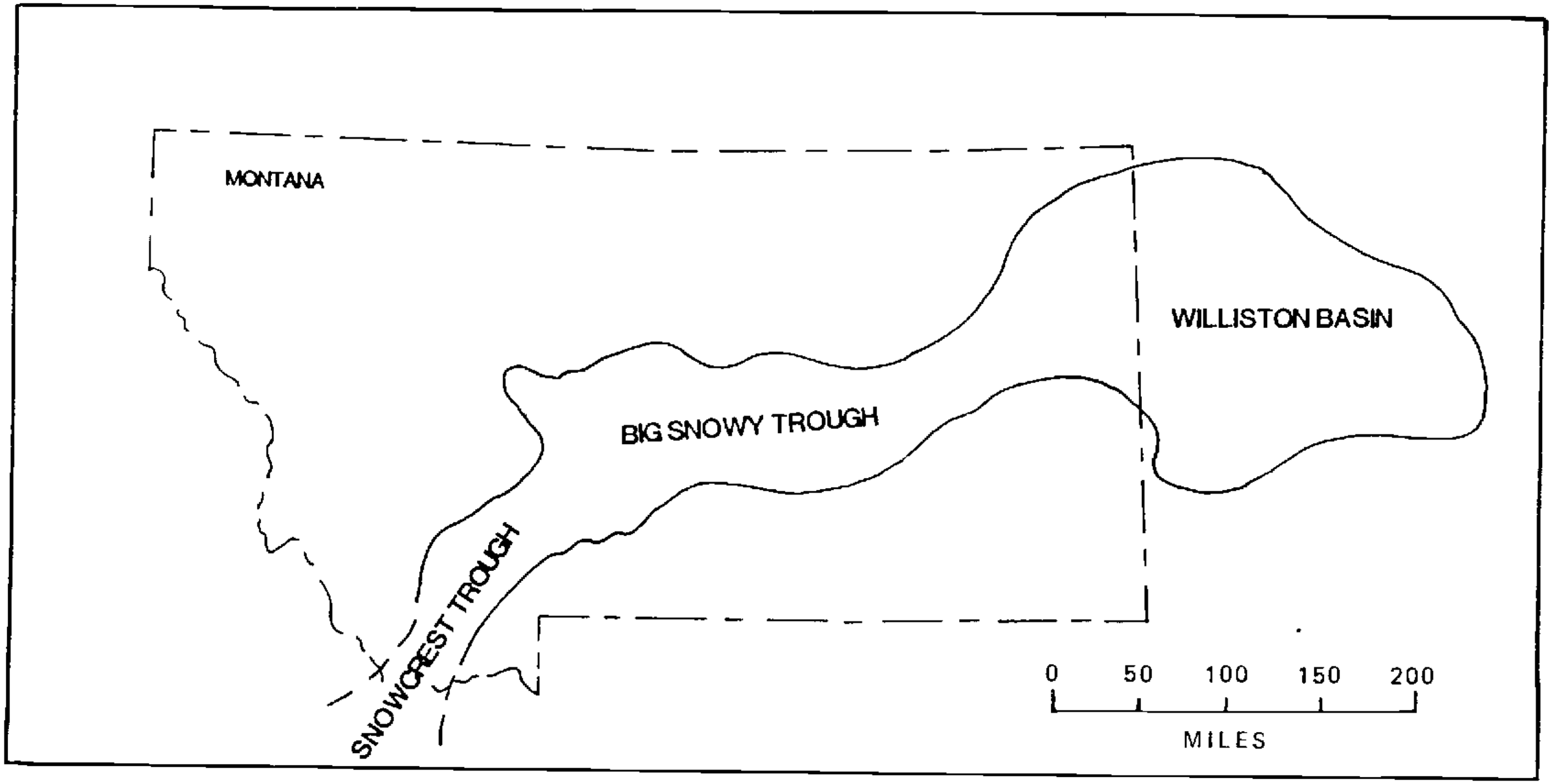


Figure 2. Late Mississippian-Early Pennsylvanian trough system across the northern Rocky Mountain Cordilleran platform in Montana.

sippian-Early Pennsylvanian interval, up to 1,500 feet of Big Snowy and Amsden sediments accumulated in the Big Snowy and Snowcrest troughs.

Of the three depositional regions, the Williston basin and the Big Snowy trough have received the most studies. This interest stems primarily from oil and gas exploration and production within the Madison-Big Snowy strata and the lower Tyler sandstones of the Amsden Group in both of these regions. As a consequence, the Late Mississippian-Early Pennsylvanian stratigraphic relationships of these producing intervals, and the adjacent units, have been established between central Montana and the Dakotas. In contrast, the area comprising the Snowcrest trough—essentially the Snowcrest Range—has received very little geologic attention, either from geologic field studies or petroleum exploration. Thus, the stratigraphic relationships of the Big Snowy and Amsden (Late Mississippian-Early Pennsylvanian) depositional sequences between the Snowcrest and Big Snowy troughs are not well understood.

PURPOSES

In light of this situation, I chose to study the Amsden and lower Quadrant Formations within the Snowcrest Range (e.g., the Snowcrest trough) in order to establish the Late Mississippian-Early Pennsylvanian stratigraphy in this part of southwestern Montana. In a concurrent Master of Science study at Oregon State University, the Big Snowy Formation in southwestern Montana has been reviewed by David Byrne (1985). Although the terms "Amsden Formation" and "Big Snowy Formation" have been used up to this point in this thesis to represent the Late Mississippian-Early Pennsylvanian rocks in southwestern Montana, these terms have just recently been replaced by a new Late Mississippian nomenclature (Wardlaw and Pecora, 1985). The new nomenclature consists of, in ascending order, the Kibbey Sandstone, Lombard Limestone (new term), and Conover Ranch Formation (new term), which together compose the Snowcrest Range Group (new term). In as much as this new terminology developed while I was in the process of researching and writing my thesis, both sets of Late Mississippian nomenclature (Big Snowy-Amsden and Snowcrest Range Group) have been incorporated in this thesis. For more information regarding the Snowcrest Range Group, please see the Development of Nomenclature section.

The main purposes of this thesis are five-fold: one, to describe ten detailed stratigraphic sections through the Amsden and lower Quadrant Formations within the Snowcrest Range and vicinity (e.g., the Snowcrest trough); two, to determine the lateral variations of thickness and lithologies of the formations; three, to reconstruct the depositional environments for the formations; four, to determine whether or not the formations can be divided into mappable units and if so, how they correlate to the stratigraphic sequences established in adjacent regions; and five, to evaluate the hydrocarbon source-rock potential of the "Amsden Formation" within the Snowcrest Range.

LOCATION AND ACCESSIBILITY

The Snowcrest Range is located in southwestern Montana and trends roughly 40 miles in a northeasterly direction through Beaverhead and Madison Counties (figure 3). In general, the range varies from low-lying, rolling hills (6,500 feet) in the southwest to steep mountainous terrain (10,000 feet+) in the northeast (figure 4). The quality of exposure also varies within the range from grass-covered, poorly exposed sections in the southwest (figure 5) to excellent, ledge- to cliff-forming sections in the northeast (figure 6). The northern limit of the Snowcrest Range is placed at Ruby Gap where the Ruby River cuts through late Paleozoic-Mesozoic exposures. North of Ruby Gap, the mountainous terrain continues as the southern part of the Greenhorn Range. Bounding the Snowcrest Range to the northwest are two Tertiary-filled downdropped basins, the Sage Creek basin to the southwest and the Ruby River basin to the northeast. To the southeast, the range is bounded by another Tertiary-filled basin, the Centennial basin. Lying to the west of the Snowcrest Range are the Tendoy and Medicine Lodge thrust sheets which compose part of the Overthrust Belt in southwestern Montana. Surrounding the Snowcrest Range are several mountain ranges of equal magnitude (see figure 3). These are, in a clockwise fashion from 12 o'clock, the Greenhorn Mountains, the Gravelly Range, the Centennial Mountains, the Tendoy Mountains, the Blacktail Mountains, and the Ruby Range. As the name implies, the Snowcrest Range retains snow patches at its higher elevations until mid-summer. The many small streams

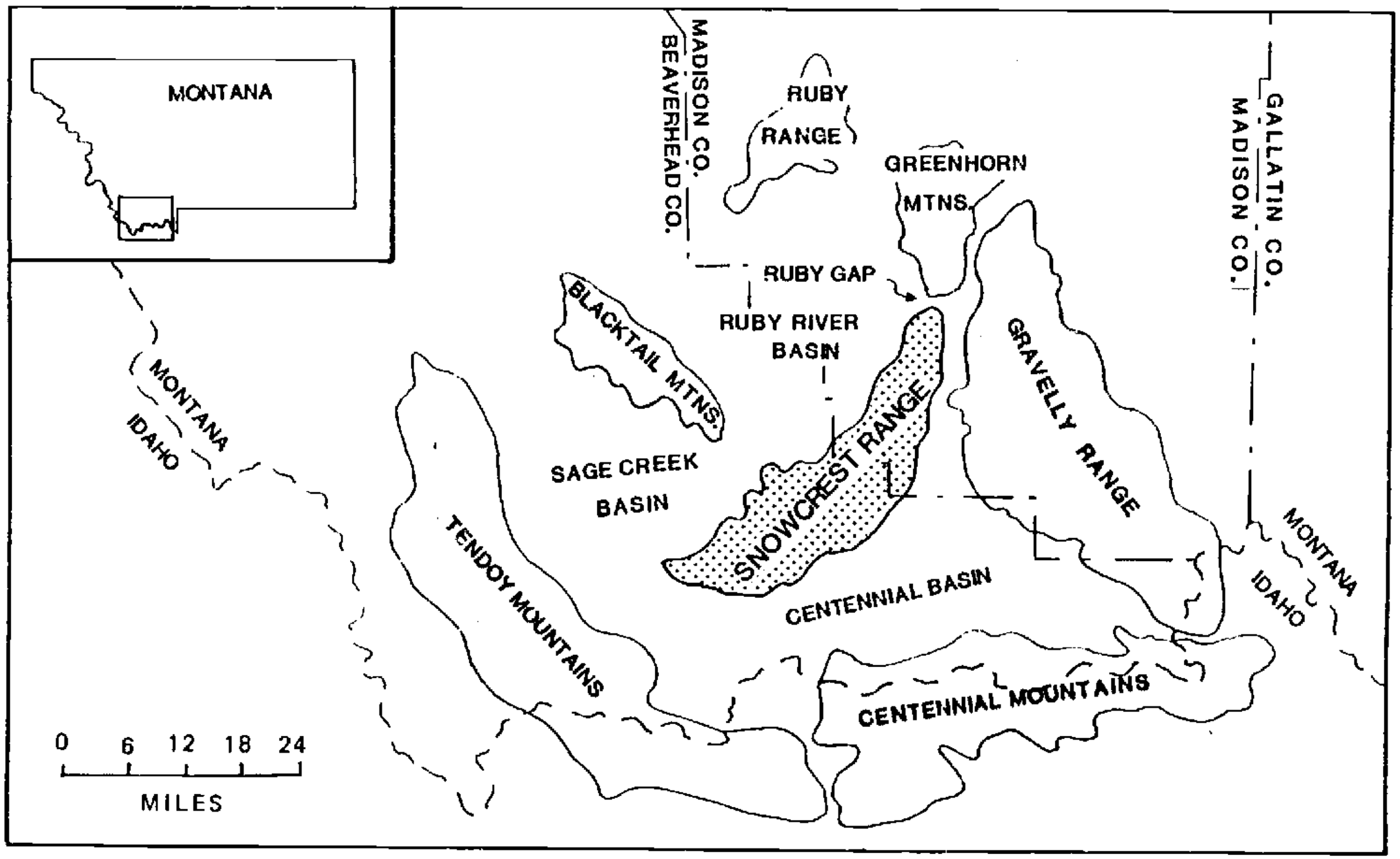


Figure 3. Outline map of basins and mountain ranges adjacent to the Snowcrest Range, southwestern Montana. Modified from Scholten, 1967.

Figure 4. View of northern Snowcrest Range from Upper Ruby River Road. Mountains from left to right are Sliderock Mountain and Spur Mountain.

Figure 5. View of poorly exposed, grass-covered section typical of exposure quality in southwestern part of the Snowcrest Range. Forested slope represents Quadrant Formation exposure. Photo taken at the Red Rock River locality looking to the southwest, Bitterroot Mountain range in background.

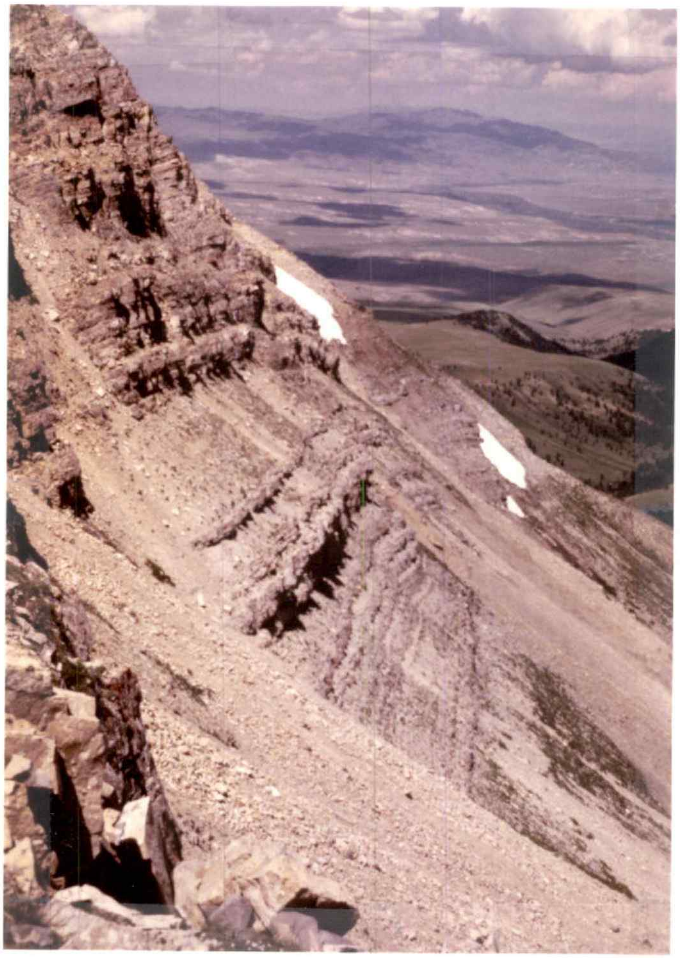


Figure 6. View of excellent, ledge- to cliff-forming exposures typical of exposure quality in northeastern part of the Snowcrest Range. Photo taken at Sliderock Mountain looking to the north over the upper Ruby River basin.

draining the range eventually feed into either the Beaverhead or Jefferson Rivers.

Access into the Snowcrest Range is limited to three Forest Service-County dirt roads (figure 7). At the southern end of the range, good access is possible along either the Lima Reservoir road out of Lima or the Blacktail Deer Creek road out of Dillon. Unfortunately, neither of these roads lead to very good exposures of Amsden or Quadrant Formations. The northern end of the range can be reached along the upper Ruby River road, originating at Alder, which serves several small Forest Service campgrounds and local ranchers. The northwestern flank of the range is accessible, weather permitting, along a network of secondary (jeep) roads up Ledford, Robb, or the east fork of the Blacktail Deer creeks. In all instances, access to adequate Amsden and Quadrant exposures within the range requires several hours of hiking from any of these roads.

Most of the Snowcrest Range lies within the boundaries of the Beaverhead National Forest. The sole exception lies at the southwestern end of the range where the land is owned by either the Bureau of Land Management, the State of Montana, or private individuals. The range encompasses parts of the Henry Gulch, Whiskey Spring, Antone Peak, Stonehouse Mountain, Swamp Creek, Spur Mountain, and Home Park Ranch 7.5 minute U.S.G.S. topographic maps.

Two sections outside of the Snowcrest Range also were measured to facilitate the study. One is located on the northwest side of Sheep Creek in the Blacktail Mountains (Gallagher Quad-

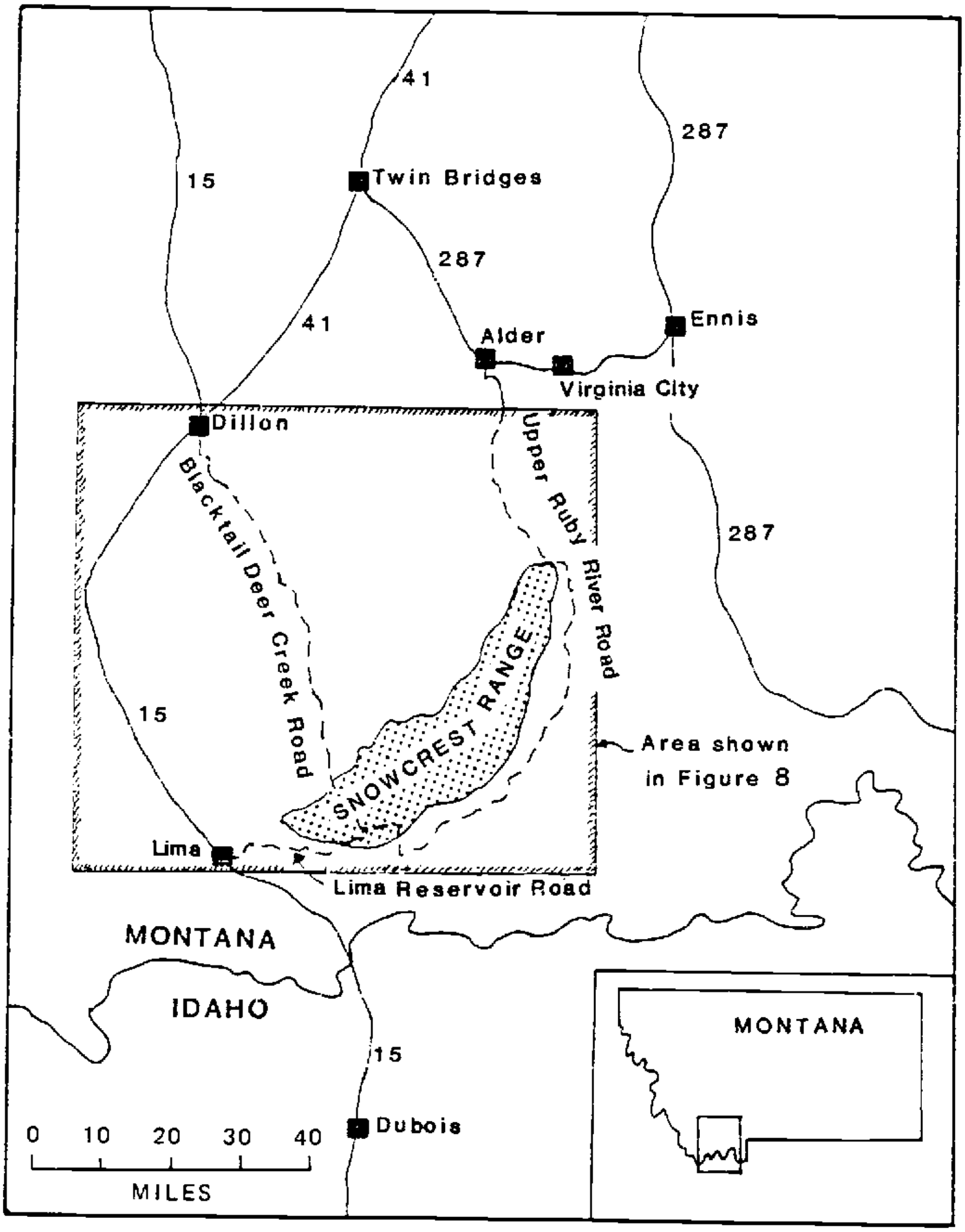


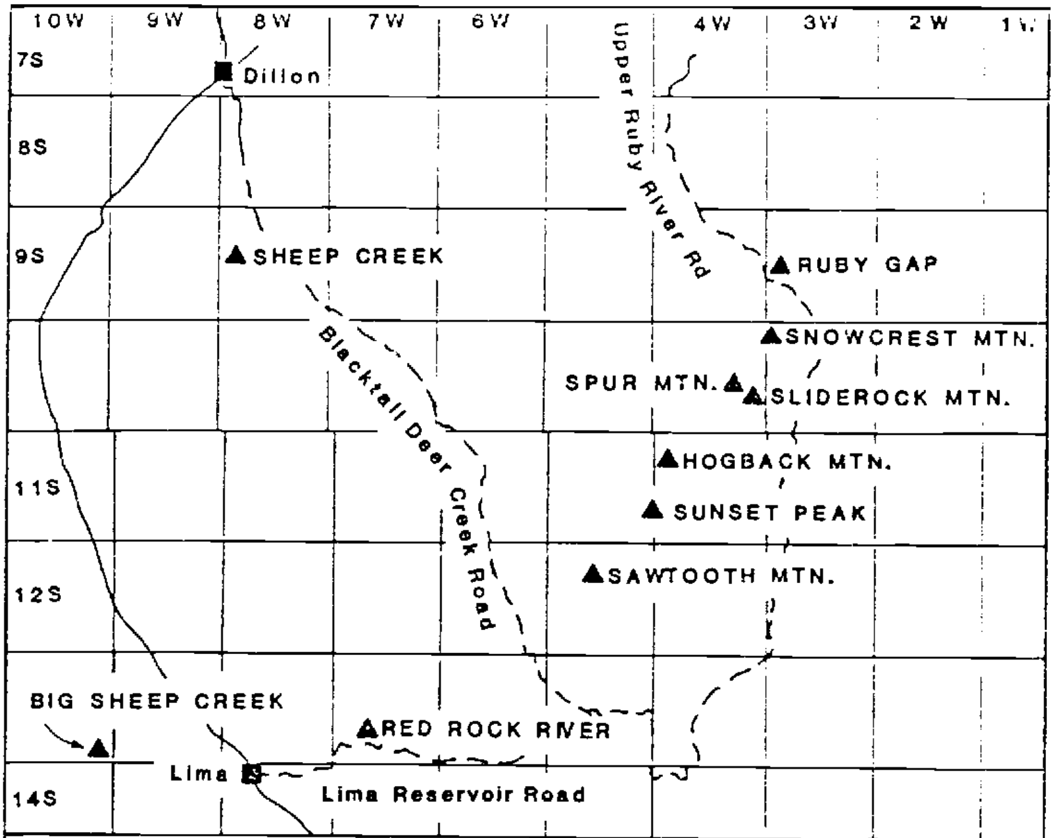
Figure 7. Outline map of towns and roadways adjacent to the Snowcrest Range, southwestern Montana.

rangle), and the other lies along the Hidden Pasture Trail north of Big Sheep Creek in the Tendoy Mountains (Dixon Mountain Quadrangle). At both localities, access to the exposures is easy although permission is required from the Conover family to examine the section within the Blacktail Mountains.

INVESTIGATIVE METHODS

The thesis field work was accomplished during the ten-week interval from June 15 to August 31, 1984. While in the field, ten stratigraphic sections through the Amsden and lower Quadrant Formations were measured. The location of each measured section (figure 8) was determined using both United States Department of Interior air photographs and a geologic map of the northern Snowcrest Range compiled by Sheedlo (1984). The geology at each measured section site was recorded on U.S.G.S. 7.5 minute topographic maps and later was enlarged to a scale of 1:12,000 (see appendix).

In the field, bedding attitudes were measured using a Brunton compass. Stratigraphic thicknesses were either measured directly using a Jacob's staff or calculated mathematically utilizing bedding attitudes, slope angles, and slope distances. Rock colors were determined using the Geological Society of America Rock-Color Chart (1979). Stratification terminology used in this thesis follows McKee and Weir's (1953) classification. The sandstones are classified according to Williams, Turner, and Gilbert (1954) while the carbonate lithologies were described using Dunham's



Sheep Creek - Sec. 18, T. 9 S., R. 8 W.
Ruby Gap - Sec. 18, T. 9 S., R. 3 W.
Snowcrest Mountain - Sec. 6, T. 10 S., R. 3 W.
Sliderock Mountain - Sec. 23 & 24, T. 10 S., R. 4 W.
Spur Mountain - Sec. 23, T. 10 S., R. 4 W.
Hogback Mountain - Sec. 7, T. 11 S., R. 4 W.
Sunset Peak - Sec. 24, T. 11 S., R. 5 W. AND Sec. 19, T. 11 S., R. 4 W.
Sawtooth Mountain - Sec. 9, T. 12 S., R. 5 W.
Red Rock River - Sec. 21, 22, & 28, T. 13 S., R. 7 W.
Big Sheep Creek - Sec. 36, T. 13 S., R. 10 W.

Figure 8. Measured section localities within thesis area. See appendix for stratigraphic descriptions.

(1962) classification.

In total, 92 thin sections were examined to aid in identifying the various fossil fragments and to assign rock names to the samples. To help identify dolomite from calcite, both "Alizarin Red S" staining and X-ray diffraction analyses of 121 rock samples were performed. The hydrocarbon source rock analyses were performed by Tenneco Oil Exploration and Production Laboratories in Houston, Texas, for which I express my deep appreciation.

REGIONAL STRUCTURAL SETTING: SOUTHWESTERN MONTANA

The present-day structural setting of southwestern Montana is characterized by the intersection of two distinct thrust fault systems: the Medicine Lodge-Tendoy thrust system and the Snowcrest-Greenhorn thrust system (figure 9). The Medicine Lodge-Tendoy thrust system strikes roughly north-south, dips to the west, and belongs to the Overthrust Belt in southwestern Montana. Structural analysis of the Tendoy thrust sheet indicates that it represents a "Sevier-type" detachment thrust involving thin-skin tectonics (Perry et al., 1983). The age of thrusting is considered to be Eocene or late Paleocene (Scholten, 1957). The amount of displacement along the Medicine Lodge and Tendoy thrusts is the subject of continuing debate, but recent studies support that "the Tendoy thrust sheet has been transported from the Cordilleran hinge line, and the Medicine Lodge sheet has been transported from possibly much further west" (Perry et al., 1983). Based on

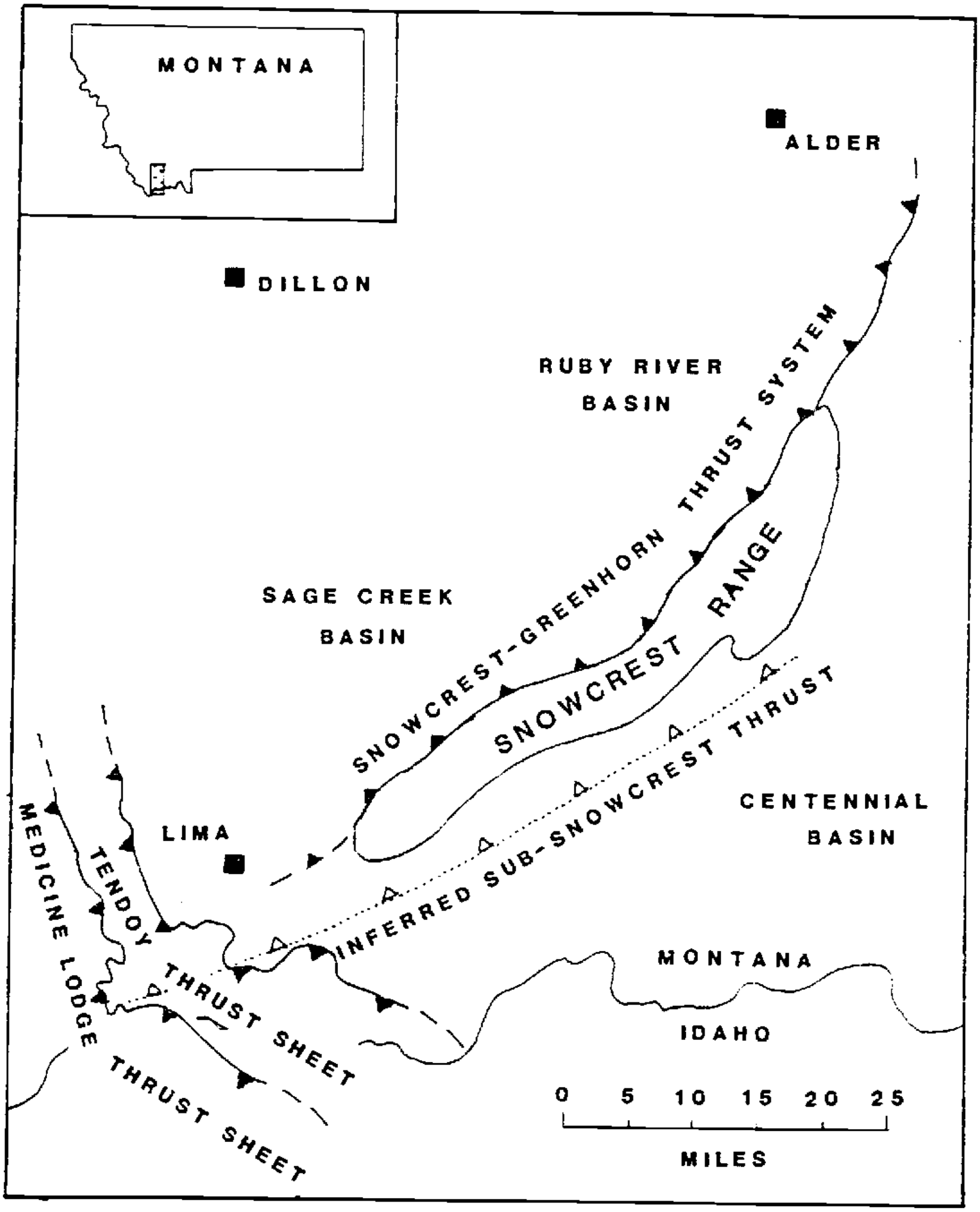


Figure 9. Present-day structural setting, southwestern Montana.

regional stratigraphic relationships within the Tendoy plate, Perry and others (1981) concluded that the Tendoy thrust sheet had been displaced less than six kilometers to the east.

In contrast to the Medicine Lodge-Tendoy thrusts, the Snowcrest-Greenhorn thrust system dips to the northwest, involves basement rocks, and is considered to have been initiated during late Early Cretaceous time (Sheedlo, 1984). The style of thrusting is believed to be related to a "thrust uplift model" in which thrusting is the ultimate cause of folding (Sheedlo, 1984).

The intersection of the two thrust systems in southwestern Montana has recently been the subject of several papers by Perry and others (1981, 1983) who speculate that an older (late Early Cretaceous), concealed sub-Snowcrest thrust, paralleling the trend of the Snowcrest-Greenhorn thrust system, extends beneath the younger (Eocene-late Paleocene) Medicine Lodge-Tendoy thrust system. As a consequence, the potential for structural hydrocarbon traps within the Overthrust Belt region in southwestern Montana is greatly enhanced. Although the sub-Snowcrest thrust as proposed by Perry and others (1981, 1983) has yet to be tested by drilling, the presence of a subsurface thrust in this region is supported by aeromagnetic data (Zietz et al., 1980) and gravity modeling (Kulik and Perry, 1982).

PREVIOUS WORK: SNOWCREST RANGE AND VICINITY

Detailed geologic field studies within the Snowcrest Range have been minimal. The thick Late Mississippian-Early

Pennsylvanian sequence in the range has been noted by many workers (Condit, 1918; Sloss, 1950; Sloss and Moritz, 1951; McMannis, 1955; Scholten, 1957; Maughan and Roberts, 1967; Sando et al., 1975; Smith and Gilmour, 1979; Perry et al., 1983; and Maughan, 1984, just to mention a few), but the sequence has never been studied extensively. The reasons for the lack of studies are primarily two-fold: first, the general inaccessibility of exposures within the range and second, the tendency for many studies to concentrate on the more publicized exposures in either the Overthrust Belt or central Montana.

Nevertheless, Condit (1918) was the first to describe the late Paleozoic stratigraphy at the northern end of the Snowcrest Range as part of a regional stratigraphic study. In his study, the strata equivalent to the Amsden Formation were not formally recognized, but were described as part of the lower Quadrant Formation.

Studies within the Snowcrest Range then were generally neglected until 1950 when Klepper published a geologic reconnaissance map and report of parts of Beaverhead and Madison Counties. Following this publication, several theses concentrating on the southwestern part of the range were completed (Brasher, 1950; Keenmon, 1950; Gealy, 1953; and Flanagan, 1958). At about the same time and continuing into the 1970's, similar field studies were completed in the surrounding ranges. To the north and east, parts of the Greenhorn and Gravelly Ranges were mapped by Mann (1950, 1954, 1960), Hadley (1960, 1980), Bubb (1961), Christie (1961), and Manske (1961). South of the Snowcrest Range, the Centennial

Mountains and basin were mapped by Honkala (1949, 1960), Moran (1971), Witkind (1972, 1975, 1976, 1977), and Murray (1973).

In the 1980's, the Snowcrest Range has become the site, once again, for new studies in southwestern Montana. Structural studies include the sub-Snowcrest thrust hypothesis by Perry and others (1981, 1983), and a structural analysis of the northern Snowcrest Range by Sheedlo (1983, 1984). Stratigraphically, the Quadrant Formation in the Snowcrest Range and vicinity (e.g., Snowcrest trough) is currently being studied by Saperstone (personal communication, 1985) and rocks equivalent to the "Big Snowy Formation" in southwestern Montana have been reviewed by Byrne (1985).

In addition, the northern part of the Ruby Range has been mapped by Tysdal (1976), the Blacktail Mountains by Pecora (1981), and parts of the Tendoy thrust sheet (Tendoy Mountains) by Hildreth (1981), Klecker (1981), and Sadler (1981).

DEVELOPMENT OF NOMENCLATURE

INTRODUCTION

The terms Amsden and Quadrant are widely used in the stratigraphic nomenclature to represent the Late Mississippian-Early Pennsylvanian rocks in Montana and Wyoming. Although each term developed in the literature more or less simultaneously, the evolution of "Amsden" nomenclature has been much more complicated than that of the Quadrant, as shown in figures 10, 11, and 14. The reasons for the numerous variations in usage for the "Amsden" stem primarily from one, a lateral variation in lithofacies; two, a general paucity of fossils in the lowermost part of the formation; and three, the fact that the "Amsden" represents a time-transgressive depositional sequence across the Cordilleran platform. When combined, these factors make both lithostratigraphic and biostratigraphic correlations between regions difficult. Adding to the confusion, the name "Amsden" has been used in both Montana and Wyoming to delineate different sedimentary assemblages and intervals of geologic time. As a consequence, there exists a "Montana version" and a "Wyoming version" of the "Amsden" in the literature. When considering an area that could have received sediment input from either a Montana terrane or a Wyoming terrane (e.g., the Snowcrest trough), problems arise in correlating the local lithologic units to either of the "Amsdens". For this reason, both the Montana and Wyoming versions of "Amsden" will be reviewed and correlations between the two

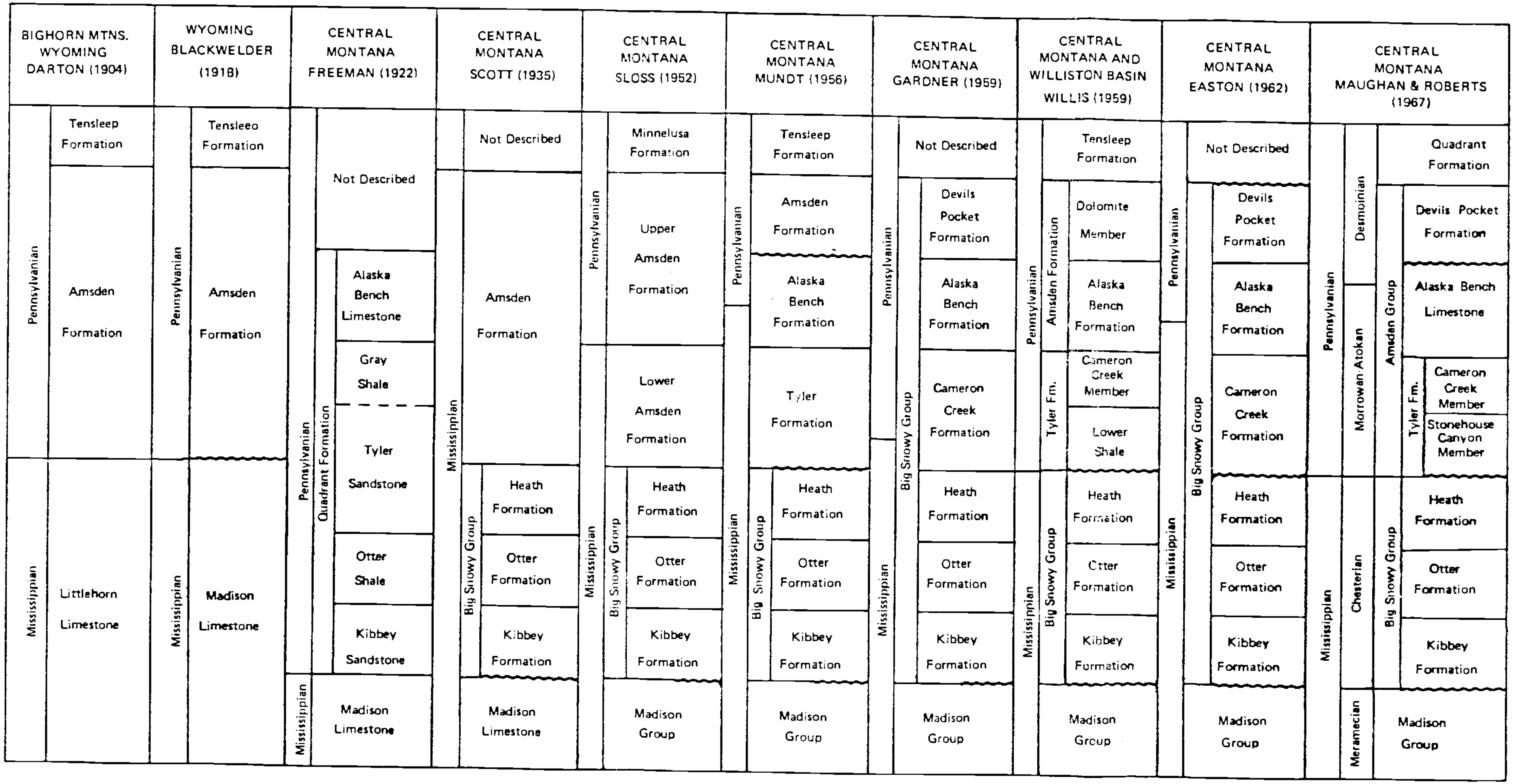


Figure 10. Nomenclatural development of the "Amsden" in Montana.

attempted.

AMSDEN GROUP: MONTANA

The Amsden Formation was first named by Darton (1904) for a variable sequence of red shales, limestones, and cherty sandstones between the Littlehorn Limestone (now Madison Limestone) and Tensleep Formation (Quadrant correlative) along the Amsden Branch of the Tongue River in the Bighorn Mountains, Wyoming. At the time, Darton assigned a Pennsylvanian age to the Amsden Formation and considered the lower contact with the Madison Limestone to be conformable. Later, this lower contact was correctly interpreted as an unconformity by Blackwelder (1918).

In Montana, the rocks equivalent to the Amsden Formation, as defined by Darton, were initially considered to be part of the Quadrant Formation (Weed, 1900; Freeman, 1922; and Reeves, 1931). Scott (1935) was the first to recognize and establish that the Amsden Formation of Wyoming could be extended northward into central Montana. Based on stratigraphic and paleontological evidence, Scott proposed a Late Mississippian (Chesterian) age for the Amsden Formation, although later (1945) he was to change this age assignment to Early Pennsylvanian (Morrowan). Scott also perceived that in central Montana there existed additional strata between the Amsden Formation and Madison Limestone that were not present in Wyoming. Therefore, he introduced the name Big Snowy Group to account for these strata which consist of, in ascending order the Kibbey, Otter, and Heath Formations.

During the 1940's and early 1950's, few studies concentrated on the Amsden Formation of Montana. As a consequence, the formation often was just informally divided in the literature into a lower sandstone-shale member and an upper carbonate-clastic member (Sloss, 1952).

The silence was broken by Mundt (1956a,b) when he referred to the lower sandstone-shale member as the Tyler Formation of Late Mississippian (Chesterian) age, and the carbonate part of the upper member as the Alaska Bench Formation which spanned the Mississippian-Pennsylvanian (Chesterian-Morrowan) boundary in central Montana. Both the names "Tyler" and "Alaska Bench" were borrowed from an earlier classification of the lower Quadrant Formation by Freeman (1922). The clastic rocks above the Alaska Bench Formation were considered to represent the Amsden Formation. Because the Heath shales are truncated at the contact with the overlying sandstones of the Tyler Formation throughout central Montana, the contact between these two formations was considered to be an unconformity. In addition, the Heath shales were viewed as representing a marine depositional sequence whereas the lower Tyler sandstones were deposited by a fluvial system (Mundt, 1956a; Norton, 1956). Within the shale sequence above the lower sandstones of the Tyler Formation, additional unconformities were recognized by Norton (1956). However, the areal extent of these unconformities in central Montana is questionable because of limited exposures. Both Mundt and Norton agreed though, that the contact between the Tyler-Alaska Bench is gradational whereas an unconformity characterized the Alaska Bench-Amsden contact.

The Carboniferous stratigraphic nomenclature in central Montana was modified again by Gardner (1959) who considered the Tyler, Alaska Bench, and Amsden Formations of Mundt (1956a,b) to be continuous downwards into the Heath Formation without being interrupted by any major unconformities. Consequently, he dropped the name "Amsden Formation" from the nomenclature of Montana, considering its use to be inappropriate and potentially confusing. In its place, he simply expanded Scott's (1935) version of the Big Snowy Group to include all the strata between the Madison Group and Quadrant Formation. In addition, Gardner introduced the name Cameron Creek Formation (Mississippian-Pennsylvanian) for a sequence of "red, purple, and brown shales, siltstones, and sandstones with some gray shales and limestones" that lay below the Alaska Bench limestone and above the Heath Formation. Incorporated within this new formation were the Tyler Formation sandstones of Mundt (1956a,b). Gardner chose not to include the name Tyler Formation in his classification as he considered this lithologic unit to be sporadic in occurrence, and therefore, not a mappable stratigraphic unit. Gardner also introduced the Devils Pocket Formation to represent "a sequence of cherty dolomites, limestones, red sandstones, and shales and chert breccia" that lay between the Alaska Bench limestone and the Quadrant Formation. Thus, the Big Snowy Group, as modified by Gardner, consisted of, in ascending order, the Kibbey, Otter, Heath, Cameron Creek, Alaska Bench, and Devils Pocket Formations. Using Gardner's classification scheme, Easton (1962) attempted to resolve the age problem for these Carboniferous formations in central Montana. Unfortunately, he could not substantiate all his assumptions, but he did speculate that the Mississippian-Pennsylvanian boundary should be placed within the Alaska Bench Limestone. He also considered that an unconformity existed at the top of the Devils Pocket Formation and conceded that an unconformity might exist between the Heath and Cameron Creek Formations, although limited in its areal extent.

Willis (1959), publishing a few months after Gardner, considered that an unconformity did exist between the Heath and Tyler Formations as defined by Mundt (1956a,b) in the central Montana-Williston basin regions. Because of this conclusion, he accepted Mundt's classification scheme rather than Gardner's and therefore restricted the use of the Big Snowy Group to only the Kibbey, Otter, and Heath Formations. In addition, Willis divided Mundt's Tyler Formation into two members: a lower dark shale member with interstratified sandstones (unnamed), and an upper red shale unit which he referred to as the Cameron Creek Member, a name adopted from an earlier Gardner publication (1950). The cherty carbonate sequence above the Tyler Formation, which he believed represented the Amsden Formation, consisted of, from bottom to top, the Alaska Bench Member and an unnamed dolomite member. In contrast to Gardner, Willis placed the Mississippian-Pennsylvanian boundary at the unconformity between the Heath and Tyler Formations, just as Mundt (1956a,b) had before him.

Maughan and Roberts (1967) addressed the Mississippian-Pennsylvanian boundary problem in central Montana and concluded, like Willis, that it occurred at the unconformity between the Heath and Tyler Formations. They also considered that the Tyler Formation could be "...divided into two members, based largely on color and partly on lithology". For the upper red shales, they carried on the use of the name Cameron Creek Member and introduced the name Stonehouse Canyon Member for "...strata composed of predominantly dark gray rocks" between the Cameron Creek Member and the Heath Formation. Within the upper Stonehouse Canyon and lower Cameron Creek Members, they found pollen spores with which they established an Early Pennsylvanian (Atokan) age for the Tyler Formation. For the underlying Heath Formation, they established a Late Mississippian (Chesterian) age based primarily on brachiopod fauna. In conjunction with this paleontological evidence and the stratigraphic relationships in central Montana, they considered that the most logical placement for the Mississippian-Pennsylvanian boundary would be at the Heath-Tyler unconformity. In addition, Maughan and Roberts chose to upgrade the Amsden Formation in central Montana to the status of a "group" consisting of, in ascending order, the Tyler Formation, Alaska Bench Limestone, and Devils Pocket Formation. However, in parts of southwestern Montana, the rock correlations to the formations of the Amsden Group of central Montana were not consistently recognized and therefore, they recommended that the formational status of the Amsden should be used in this region.

Today in central Montana, the stratigraphic nomenclature proposed by Maughan and Roberts (1967) for the "Amsden" is generally accepted despite a continuing debate on the ages they assigned to the Tyler Formation and Alaska Bench Limestone. As they suggested, in southwestern Montana, the strata are referred to as the Amsden Formation and are loosely correlated to the central Montana correlatives. However, just recently, Wardlaw and Pecora (1985) have proposed a new Late Mississippian-Early Pennsylvanian classification scheme for rocks in southwestern Montana, the implications of which will be discussed later in this text.

AMSDEN FORMATION: WYOMING

Stemming from Darton's (1904) original work on the Amsden Formation in Wyoming, Blackwelder (1918) introduced the name "Dorwin sandstone member.....from Dorwin Peak in the Gros Ventre Range" for a widespread, cross-bedded sandstone at the base of the Amsden Formation. He also interpreted the contact between the Madison Limestone and Amsden Formation to be an unconformity. However, Blackwelder did make an apparent spelling mistake in the name of the sandstone member, and it was left unmodified for nearly thirty years before Richmond in 1945 finally corrected the spelling of "Dorwin" to "Darwin". Based on regional stratigraphic relationships, Blackwelder favored an Early Pennsylvanian age for the Darwin sandstone. Above the Darwin sandstone and below the Tensleep Formation (Quadrant correlative), he simply divided the rest of the Amsden Formation into a lower red shale unit and an upper carbonate sequence (figure 11).

Branson (1936), working in the Wind River Range, considered

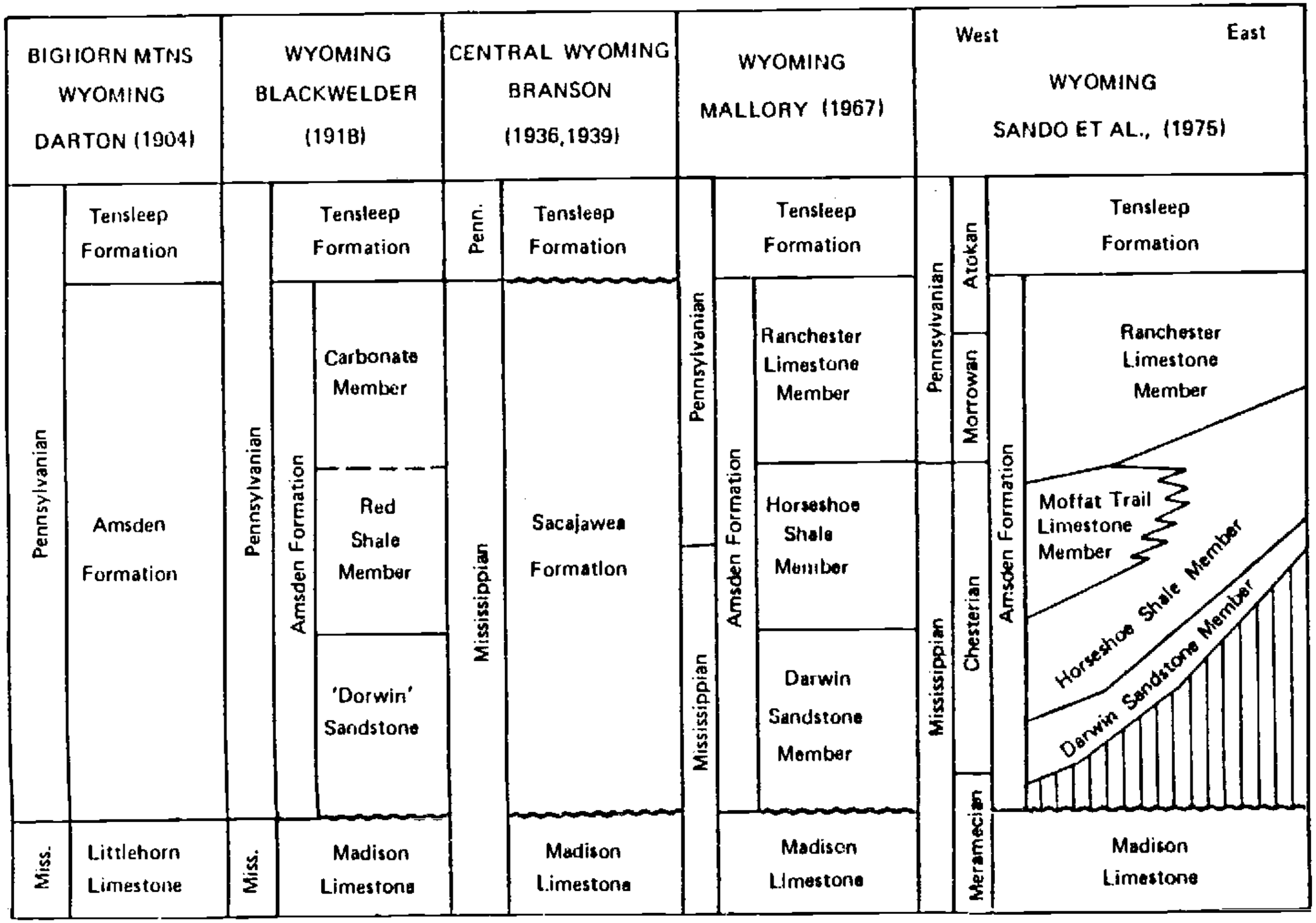


Figure 11. Nomenclatural development of the "Amsden" in Wyoming.

the Amsden Formation, as defined by Darton, to include both Mississippian and Pennsylvanian strata. Because of this situation, he felt that the Carboniferous stratigraphic nomenclature in Wyoming required revision, and he proposed the name Sacajawea Formation to represent the Mississippian sequence. Later (Branson, 1939), he suggested that the Tensleep Formation should be extended downward to the top of the Sacajawea Formation, thereby eliminating the term "Amsden" from the stratigraphic nomenclature of central Wyoming. However, despite its original intentions, the term Sacajawea soon was beset by numerous stratigraphic correlation discrepancies, and eventually its use was abandoned by most geologists.

Ignoring Branson's attempt, the Amsden Formation was not significantly modified from Blackwelder's earlier classification in the literature until Mallory, in 1967, formally divided the formation into three lithologic members. These members are, in ascending order, the Darwin Sandstone, the Horseshoe Shale, and the Ranchester Limestone. Based on paleontology, Mallory concluded that the Amsden Formation spanned the Mississippian-Pennsylvanian boundary. More specifically, the Darwin Sandstone was assigned a Late Mississippian (Chesterian) age, the Horseshoe Shale was of both Mississippian and Pennsylvanian (Chesterian-Morrowan) ages, and the Ranchester Limestone represented an Early Pennsylvanian (Morrowan-Atokan) age.

In an extensive biostratigraphic study of the Amsden Formation in Wyoming, Sando and others (1975) slightly modified the ages and nomenclature of the three-member scheme proposed earlier by Mallory. In their study, they divided the Amsden Formation into four members and assigned to each member, presented in ascending order, the following ages: the Darwin Sandstone, late Meramecian-late Chesterian age; the Horseshoe Shale, early Chesterian-Morrowan age; the Moffat Trail Limestone (new member), middle to late Chesterian age; and the Ranchester Limestone, late Chesterian-Atokan age. The Moffat Trail Limestone Member is restricted to western Wyoming; therefore, in central Wyoming, the three-member scheme of the Amsden Formation is advocated. In addition, these members represent diachronous units across Wyoming as a result of an "Amsden Sea" transgression from west to east. As a consequence, the stratigraphic position of the Mississippian-Pennsylvanian boundary across Wyoming changes form being within the Ranchester Limestone in the west to within the Horseshoe Shale in the central part of the state. At the present time, this four-member classification of the Amsden Formation of Wyoming is adopted by most workers.

COMBINING THE "AMSDENS"

When comparing the ages and nomenclature of the "Amsden" across the Montana-Wyoming border, the stratigraphic relationships between the two regions are not always apparent. Even in recent publications (Lageson et al., 1979) the authors cannot always agree on the ages or stratigraphic correlations of the "Amsden" between Montana and Wyoming. However, these relationships, as they existed in the literature in the mid-1970's, can best be illustrated in a correlation chart (figure 12). From this chart, it can be seen that the name "Amsden" has been used in the literature to delineate two distinct sedimentary assemblages which spanned different intervals of geologic time.

However, as previously stated, despite the general use of Maughan and Roberts' 1967 classification of the Amsden Group in central Montana, the ages they assigned to the Tyler Formation and Alaska Bench Limestone have not received the same endorsement. In light of this situation, new paleontological studies, concentrating heavily on conodont data, have been undertaken throughout Montana in an attempt to independently resolve the ages for these particular formations. The preliminary results from these studies indicate that the Mississippian-Pennsylvanian boundary in central Montana should be placed within the Alaska Bench Limestone and not at the Heath-Tyler unconformity (Davis, 1983, 1984). In southwestern Montana, Wardlaw and Pecora (1985), believe that the position of the Mississippian-Pennsylvanian boundary is not even within the Amsden Formation, but lies within the lowermost part of the Quadrant Formation! If this is the case, then the "Amsden" of Montana is a time transgressive unit, just as it is in Wyoming, with the stratigraphic position of the Mississippian-Pennsylvanian boundary changing across the state from west to east. Additionally, Wardlaw and Pecora (1985) state that the

> "Presently available nomenclature applied to rocks equivalent to the Amsden Formation of Wyoming and to the dominantly clastic rocks of the Big Snowy Group and lower part of the Amsden Group in central Montana (Sando and others, 1975) does not adequately apply to rocks dominated by carbonates in southwest

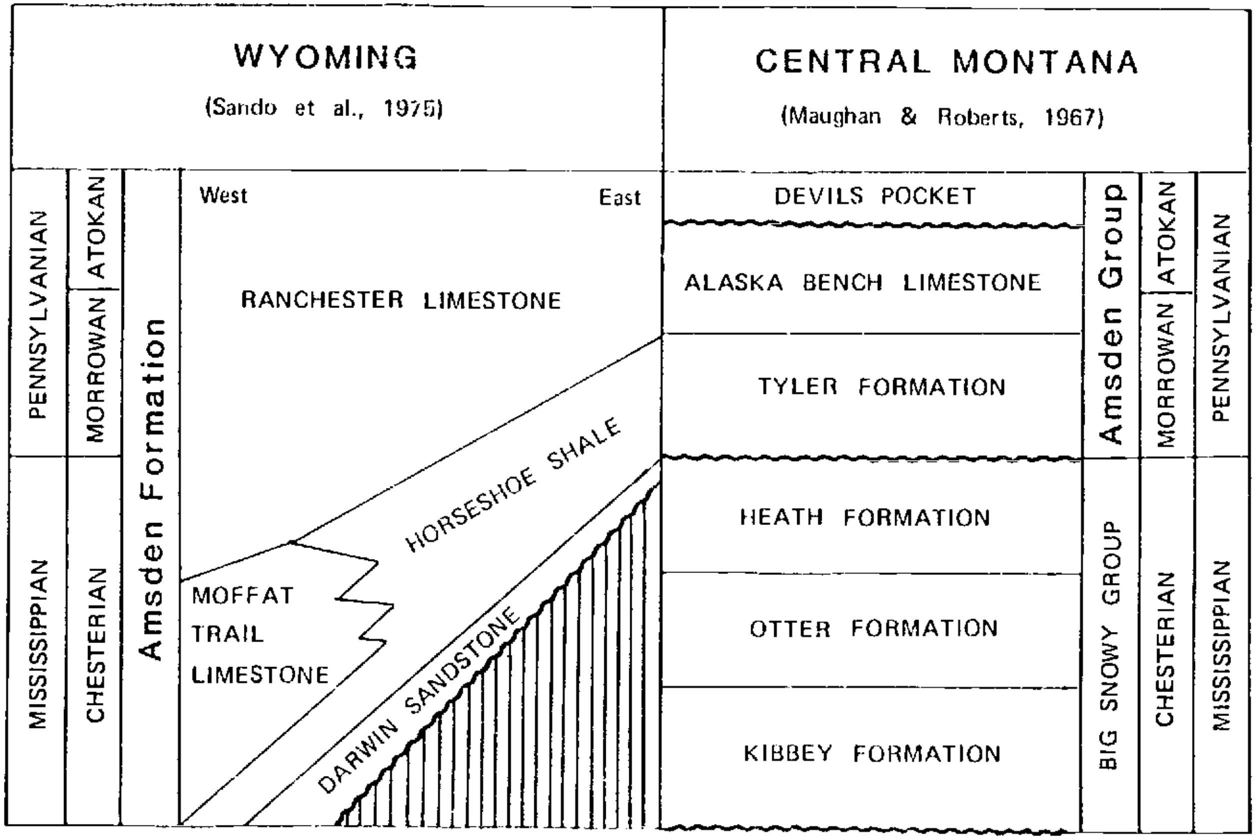


Figure 12. Relationship of the "Amsden Group" to the "Amsden Formation" between Montana and Wyoming as it exsisted in the literature during the mid-1970's.

> Montana and adjacent Idaho. For this reason, the new name Snowcrest Range Group is proposed for these southwest Montana rocks."

As they define the Snowcrest Range Group, it represents rocks of only Late Mississippian (Meramecian-Chesterian) age in southwestern Montana and consists of, in ascending order, the Kibbey Sandstone, the Lombard Limestone, and the Conover Ranch Formation. The Kibbey Sandstone (Meramecian) is stratigraphically equivalent to the Kibbey Formation in central Montana and consists of red siltstones and sandstones. The Lombard Limestone (late Meramecian to late Chesterian) is stratigraphically equivalent to the Otter, Heath, and lowermost Tyler Formations in central Montana and consists primarily of dark, micritic limestones. The name "Lombard" was borrowed from Blake (1959) who introduced the term to represent a similar limestone sequence exposed in the Bridger Range between the Big Snowy and Snowcrest troughs. The Conover Ranch Formation (late Chesterian) consists primarily of "...pale-reddish-brown to pale-reddish-purple mudstone" with lesser amounts of "...thin-bedded marine limestone and calcareous sandstone and siltstone" which are stratigraphically equivalent to the upper part of the Tyler Formation and lower part of the Alaska Bench Limestone in central Montana. The type section for the Conover Ranch Formation is located on the northwest side of Sheep Creek Canyon in the Blacktail Mountains in the northwest corner of the thesis area. The stratigraphic relationships discussed above, and an interpretive stratigraphic correlation of the Snowcrest Range Group to the Amsden Formation of western Wyoming, are shown in figure 13.

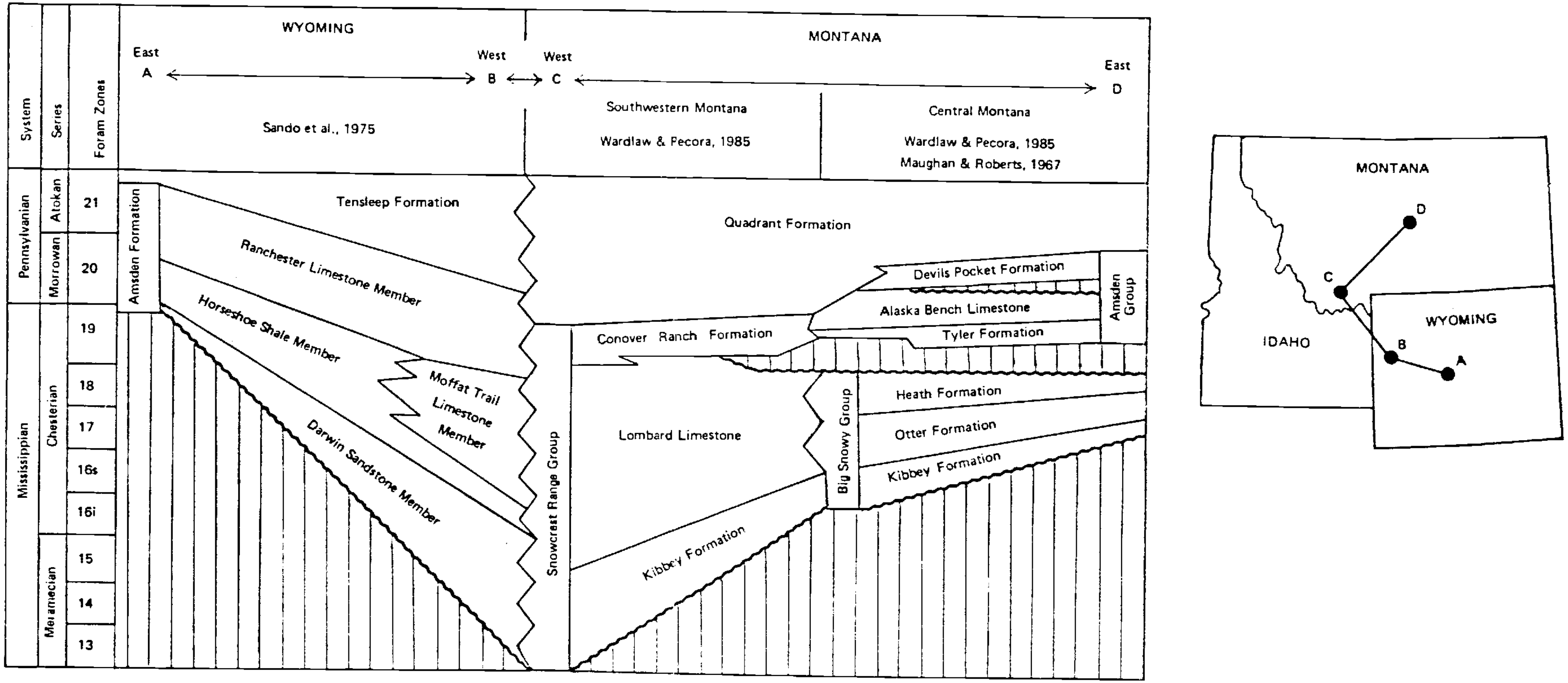


Figure 13. Combining the "Amsdens" across the Montana-Wyoming border.

QUADRANT FORMATION

The Quadrant quartzite (Formation) was named by Iddings and Weed during a ten year (1883-1893) geological survey of Yellowstone National Park. In their subsequent report, which was not published until 1899, they designated "Quadrant Mountain in the Gallatin Range" as the type locality for the "Quadrant" and considered the unit to represent both Mississippian and Pennsylvanian strata. Prior to this report being published, Peale in 1893, with the consent of Iddings and Weed, used the name Quadrant Formation to represent a sequence of red and cherty limestones with interbedded quartzites in the vicinity of Three Forks, Montana. Therefore, in the literature, even though Peale was the first to actually publish the name "Quadrant", he did not name the unit! Later, Weed (1899,1900) extrapolated the Quadrant Formation into central Montana for "...a variable sequence of sandstones, shales, and limestones." In this sequence, he named the lower sandstones the "Kibbey" and considered them to rest unconformably upon the Madison Limestone. Above the Kibbey sandstones, he referred to the predominantly dark shales as the "Otter". Weed also assigned a "lower Carboniferous" age to the Quadrant Formation based on fossils found within the Otter shale (figure 14).

Freeman (1922), expanding upon the Quadrant Formation of Weed in central Montana, introduced the names Tyler sandstone and Alaska Bench limestone to account for lithologic units above the Kibbey sandstones and Otter shales. He speculated that the

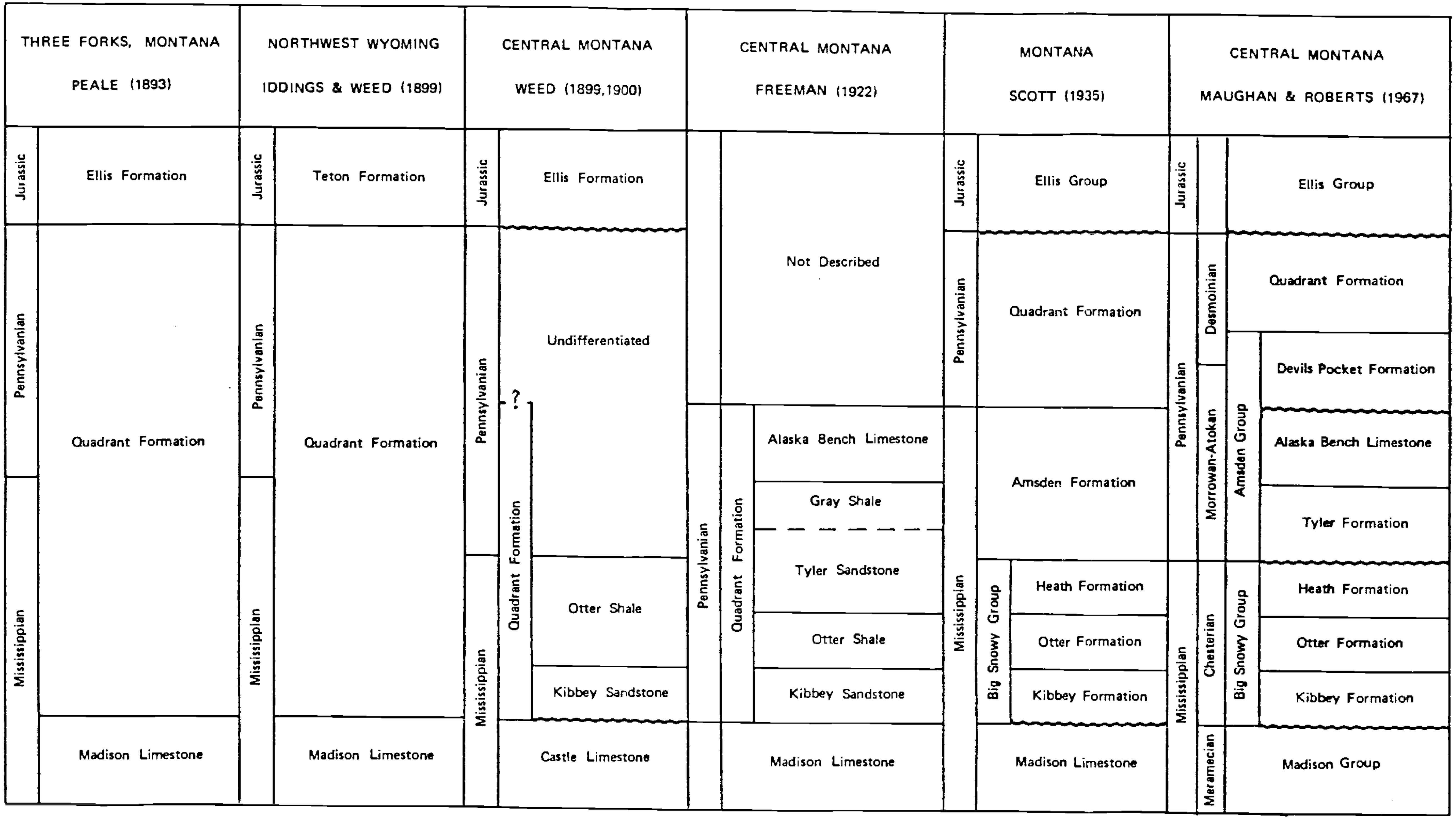


Figure 14. Nomenclatural development of the Quadrant Formation.

Quadrant Formation was Pennsylvanian in age and that the lower contact with the underlying Madison Limestone was conformable.

Scott (1935) reevaluated the Quadrant Formation type section in the Gallatin Range and revealed that the lower part of the original Quadrant Formation of Iddings and Weed (1899) incorporated the Amsden Formation as defined by Darton (1904). He, therefore, redefined the Quadrant Formation to consist only of a "...well-bedded, white to pink, fine- to medium-grained quartzite" at the type locality which represented "...a westward extension of the Tensleep" Formation. Assuming this stratigraphic relationship, he assigned a Pennsylvanian age to the Quadrant Formation, based on fossils collected and dated from the Tensleep Formation. In addition, while working in central Montana, Scott recognized that an erosional unconformity had removed most of the Quadrant Formation. Therefore, he pointed out that Weed (1900) and Freeman (1922) has misused the term Quadrant Formation to represent the stratigraphic units in this region. As a consequence, he reevaluated their work and concluded that their Quadrant Formation actually consisted of the Amsden Formation and an underlying, unnamed sequence of strata which he called the Big Snowy Group.

Since Scott's reclassification of the Quadrant Formation, the name has become widely used in the stratigraphic nomenclature of Montana. Despite a general lack of fossils within the formation, its age has been confirmed as being Pennsylvanian (Atokan to Desmoinian) based on fusulinids (Thompson and Scott, 1941) and foraminifera (Henbest, 1954, 1956). As previously mentioned, the Quadrant Formation in southwestern Montana apparently straddles the Mississippian-Pennsylvanian boundary in its lowermost beds (Wardlaw and Pecora, 1985). However, this relationship appears to be a localized occurrence and can readily be explained if one considers the Quadrant Formation to represent a west to east diachronous deposit, just like the "Amsdens".

STRATIGRAPHIC NOMENCLATURE USED IN THESIS

A slightly modified version of the stratigraphic nomenclature proposed by Wardlaw and Pecora (1985) is adopted to represent the rocks equivalent to the "Amsden" and Quadrant Formations in the thesis area (figure 15). As shown in figure 15, the sequence consists of, in ascending order, the Conover Ranch Formation (uppermost formation of the Snowcrest Ranch Group), an unnamed limestone unit, and the Quadrant Formation. Additionally, the Quadrant Formation is informally divided into a lower dolomitic interval and an upper quartz arenite interval. Beneath the Conover Ranch Formation, the other formations composing the Snowcrest Range Group (Kibbey Sandstone and Lombard Limestone) are recognized but not discussed in this thesis. The only major change from Wardlaw and Pecora's classification is that the contact between the Conover Ranch Formation and Lombard Limestone is considered to be unconformable. The limestone unit between the Conover Ranch and Quadrant Formations was left unnamed to avoid complicating any further the Late Mississippian- Early Pennsylvanian stratigraphic nomenclature in southwestern Montana. However, it is strongly believed that this limestone unit will have to be formally

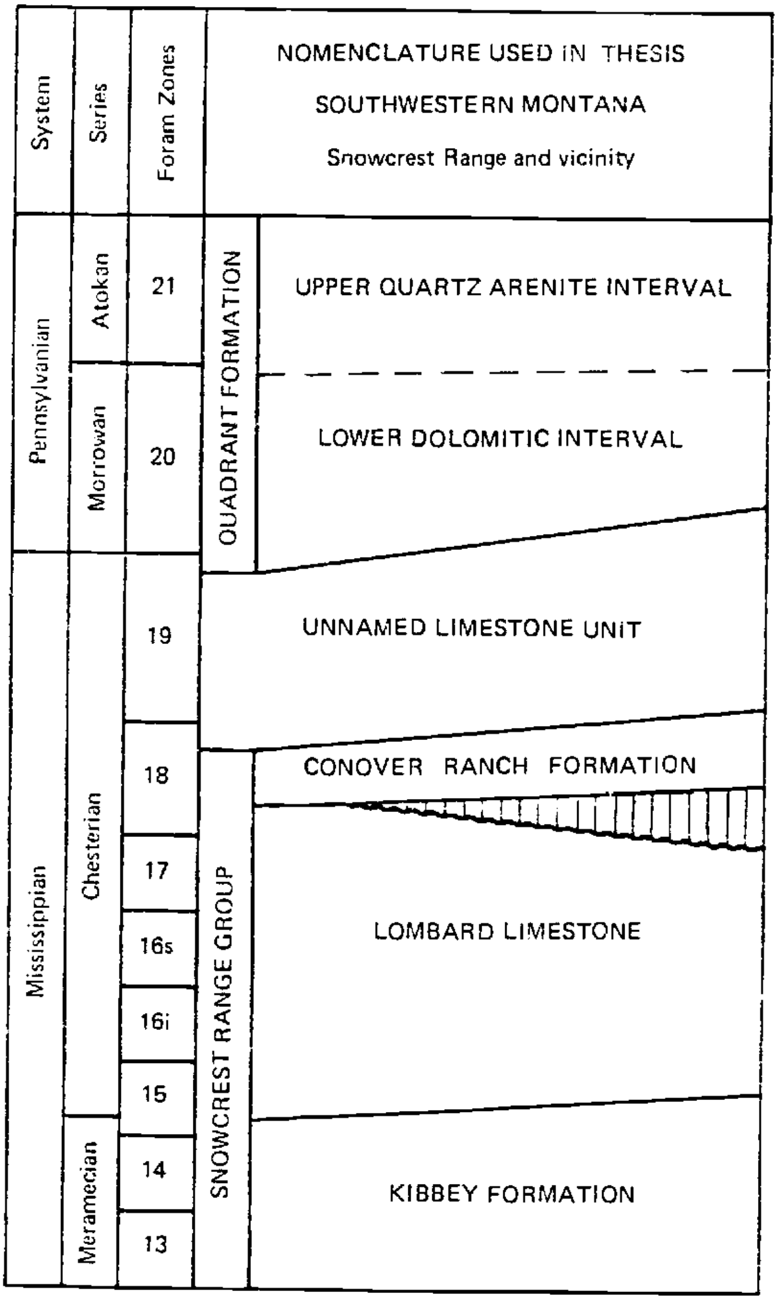


Figure 15. Stratigraphic nomenclature used in thesis.

recognized and incorporated into the Snowcrest Range Group either as a member or separate formation in future studies in order to accurately represent the Late Mississippian-Early Pennsylvanian lithologic sequences in southwestern Montana.

PALEOTECTONIC SETTING

During Late Mississippian and Early Pennsylvanian time, southwestern Montana was the site of extensive shallow water clastic and carbonate sedimentation in a trough on the western margin of the Cordilleran platform. The trough has been referred to variously as the Ruby trough (Peterson, 1981), Blacktail trough (Pecora, 1981), and Snowcrest trough (Maughan and Roberts, 1967). In recent publications, the name Snowcrest trough is favored and therefore, this name will be adopted in this thesis.

The Snowcrest trough represents a southwestern extension of the intracratonic basins that developed through Montana during the late Paleozoic which include the Big Snowy trough and the Williston basin (figure 16). Separating the Big Snowy and Snowcrest troughs was the Lombard arch (Blake, 1959; Guthrie, 1984), a late Paleozoic positive paleotectonic element which caused depositional thinning to occur between the two troughs. Bordering the Snowcrest trough to the southeast was the Beartooth platform, a relatively stable northwestern extension of the Wyoming shelf into southwestern Montana. The Beartooth platform probably represented the westernmost extension of the southern Montana arch documented by Sando and others (1975). To the west, the Snowcrest trough opened up into the Cordilleran miogeosyncline.

The Snowcrest trough developed during Late Mississippian time in response to differential subsidence on the Cordilleran platform which coincided with preexisting structurally weak zones in the underlying Precambrian basement (Maughan and Perry, 1982). The

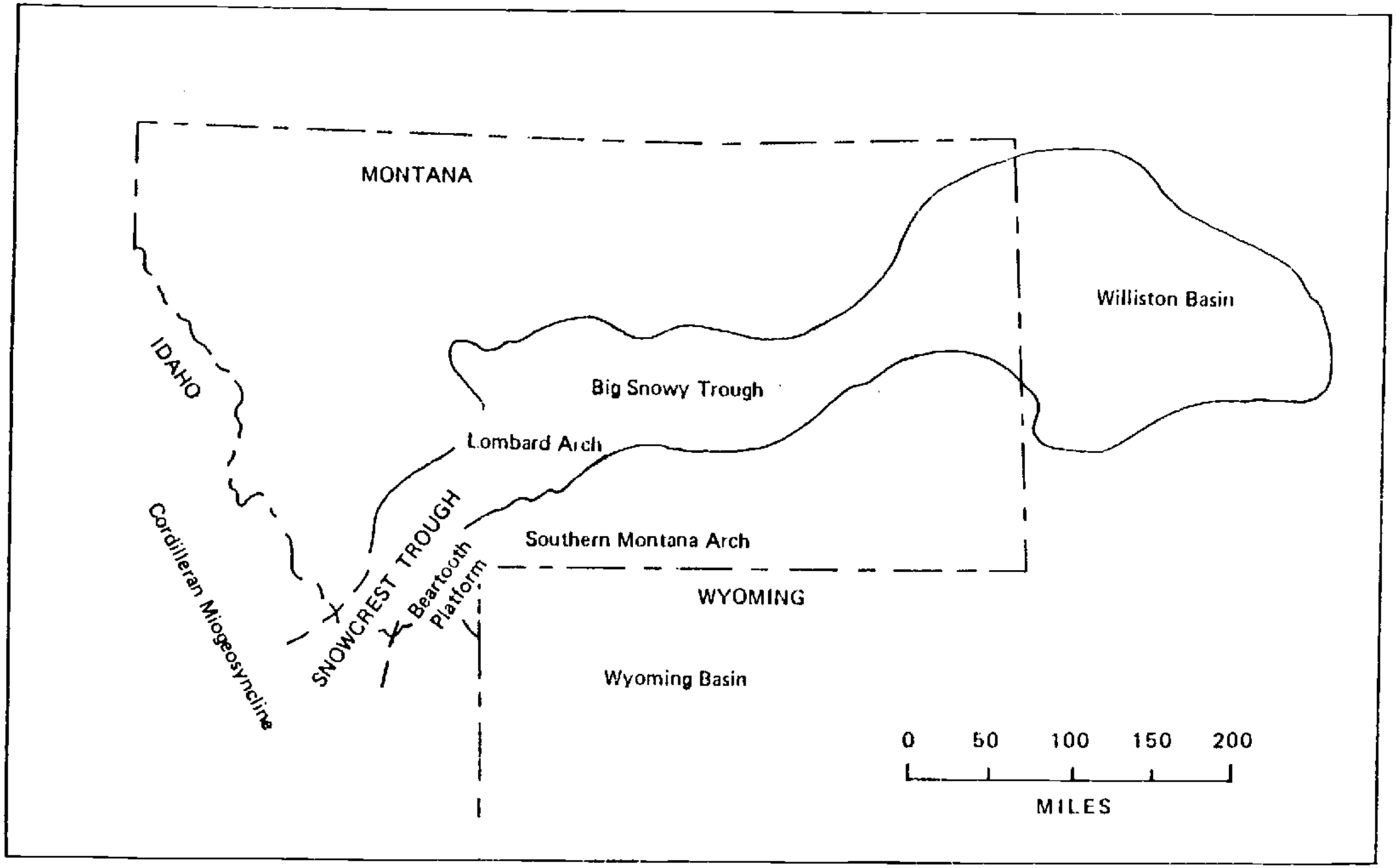


Figure 16. Late Mississippian-Early Pennsylvanian paleotectonic setting across Montana.

origin of the weakness zone has recently been attributed to the development of an incomplete aulacogen on the late Paleozoic western margin of North America (Maughan, 1984). Along the weakness zone, a series of late Paleozoic, northeast-trending, high angle faults are believed to have developed and marked the Snowcrest trough-Beartooth platform transition. Today, this transition zone coincides approximately with the northeast trend of the Snowcrest-Greenhorn thrust fault system. According to Maughan and Perry (1982), "the Snowcrest terrain (trough region) .....seems to represent a relatively unstable pre-Laramide, northeast-trending, downthrown block at the margin of the Wyoming shelf (Beartooth Platform)". In addition, they state "this block did not subside uniformily, but was broken by small northwest-trending faults developed during deposition of the upper Paleozoic sequences".

Accordingly, the Late Mississippian-Early Pennsylvanian strata across the Snowcrest-Greenhorn thrust fault system, from the Snowcrest Range to the Gravelly Range, show a dramatic thickness change (approximately from 1500 to 125 feet). This abrupt change is in part the result of different trough to platform sedimentation rates but also reflects the results of post-depositional, Laramide-age, southeastward structural telescoping along the Snowcrest-Greenhorn thrust system. The extent of this telescoping is considered to represent at least 15 kilometers in the southern Snowcrest Range (Kulik and Perry, 1982). Additionally, the southwestern extension of the Snowcrest trough in the Tendoy Mountains also has been modified by eastward thrusting along the Tendoy and Medicine Lodge thrust sheets.

STRATIGRAPHIC INTERPRETATIONS

In this chapter, lithologic descriptions, environmental interpretations, and ages are presented for each of the stratigraphic units recognized in the thesis area. These stratigraphic units are, in ascending order, the Conover Ranch Formation, an unnamed limestone unit, and the lower dolomitic part of the Quadrant Formation. Within the text, the stratigraphic units will be described from oldest to youngest. In order to facilitate the study, each of the stratigraphic units has been informally divided into several characteristic lithologic units for which lithologies, depositional environments, and ages are subsequently described in separate sections within the text. Also included are several sections devoted to the characteristics of the contacts between adjacent stratigraphic units in the thesis area.

CONOVER RANCH FORMATION

The Conover Ranch Formation rarely crops out in the thesis area, with most stratigraphic intervals forming grass-covered saddles between the more resistant Lombard Limestone below and an unnamed limestone unit above. However, the formation is adequately exposed at its type section along Sheep Creek in the Blacktail Mountains (figure 17). In the thesis area, the formation ranges in thickness from 118 feet at the type locality to 652 feet at Big Sheep Creek in the Tendoy Mountains. However, in the Snowcrest Range, a more consistent thickness (250-371 feet) is recorded

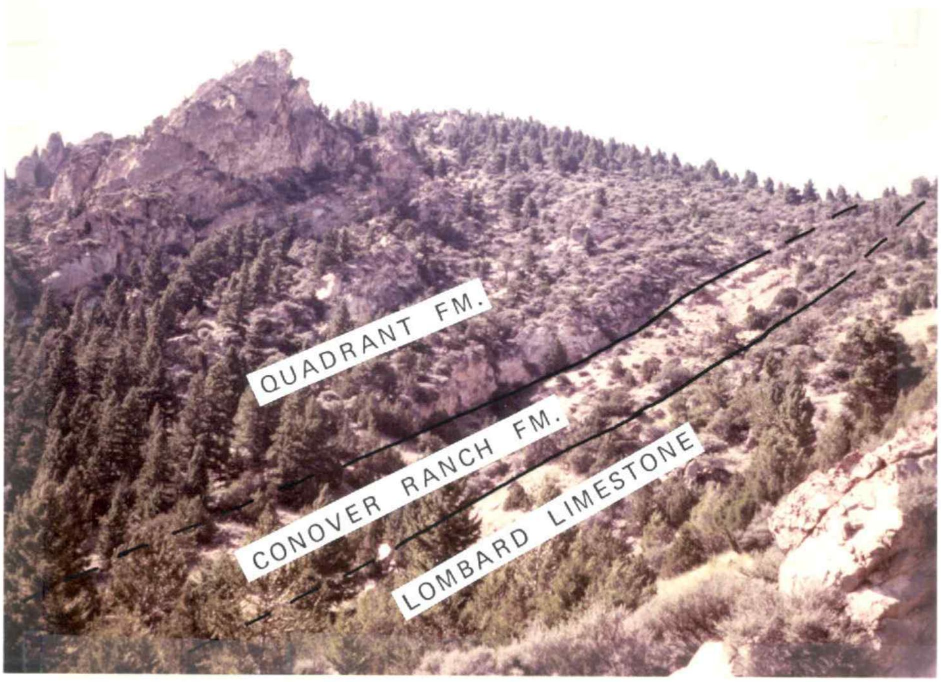


Figure 17. Type section of the Conover Ranch Formation along Sheep Creek Canyon in the Blacktail Mountains.

between Sawtooth and Sliderock Mountains.

For the purposes of review, the formation is divided into two lithologic units: one, a shale-siltstone unit, and two, a quartz arenite-limestone conglomerate unit. In addition, a grainstone lithology is recognized within the quartz arenite-limestone conglomerate unit. The shale-siltstone unit dominates the Conover Ranch Formation and is recognized throughout the thesis area whereas the quartz arenite-limestone conglomerate unit crops out sporadically as resistant lenses within the shale-siltstone unit. The regional distribution and thicknesses of the Conover Ranch Formation in the thesis area are shown on plate 1.

Conover Ranch (Amsden)-Lombard Limestone Contact

Throughout most of Montana, the Amsden Group and its southwestern correlative, the Conover Ranch Formation, are underlain, respectively, by the Heath Formation and the Lombard Limestone. Exceptions to this rule occur in the vicinity of the Lombard arch (Blake, 1959; Brewster, 1984), the southern Montana arch (Sando et al., 1975), and along the margins of the Big Snowy trough where the Amsden rests unconformably upon either the Madison Group or the Kibbey Formation (Harris, 1972). In central Montana, the Amsden and Big Snowy Groups are separated by a regional unconformity (Maughan & Roberts, 1967; Jensen & Carlson, 1972; and Sando et al., 1975). Maughan and Roberts considered this unconformity to coincide with the Mississippian-Pennsylvanian boundary. However, recent conodont studies indicate that this unconformity actually represents a intra-Late Mississippian event with the correct location of the Mississippian-Pennsylvanian boundary being placed stratigraphically higher within the Alaska Bench Limestone of the Amsden Group (Davis, 1983, 1984).

In southwestern Montana, the regional unconformity at the base of the Amsden Formation (Conover Ranch Formation) is not recognized southwest of Baldy Mountain in the Greenhorn Range by Sando and others (1975). They present evidence to support this statement by noting that sequential foraminiferal zones are recognized through late Mississippian-Early Pennsylvanian strata to the southwest of Baldy Mountain along the Montana-Idaho border. However, field evidence in the Snowcrest Range suggests that the unconformity at the base of the Conover Ranch Formation should probably be extended at least to Sawtooth Mountain, some 30 miles farther to the southwest than the Sando and others (1975) projection.

At Sawtooth Mountain, there is an excellent exposure of the Conover Ranch-Lombard Limestone contact (figure 18). At this locality, not only is there a lithologic break from micritic limestones of the Lombard Limestone to calcite-cemented quartz arenites of the Conover Ranch, but an undulatory surface characterizes the contact (figure 19). The contact appears to be erosional as it truncates the uppermost stratum of the Lombard Limestone. In addition, several small Lombard Limestone rip-up clasts were observed on the basal surfaces of the undulatory contact. Unfortunately, elsewhere in the Snowcrest Range, the contact between the Lombard Limestone and the Conover Ranch

Figure 18. Exposure of the Conover Ranch-Lombard Limestone contact at Sawtooth Mountain. One inch increments along tape highlighted for scale.

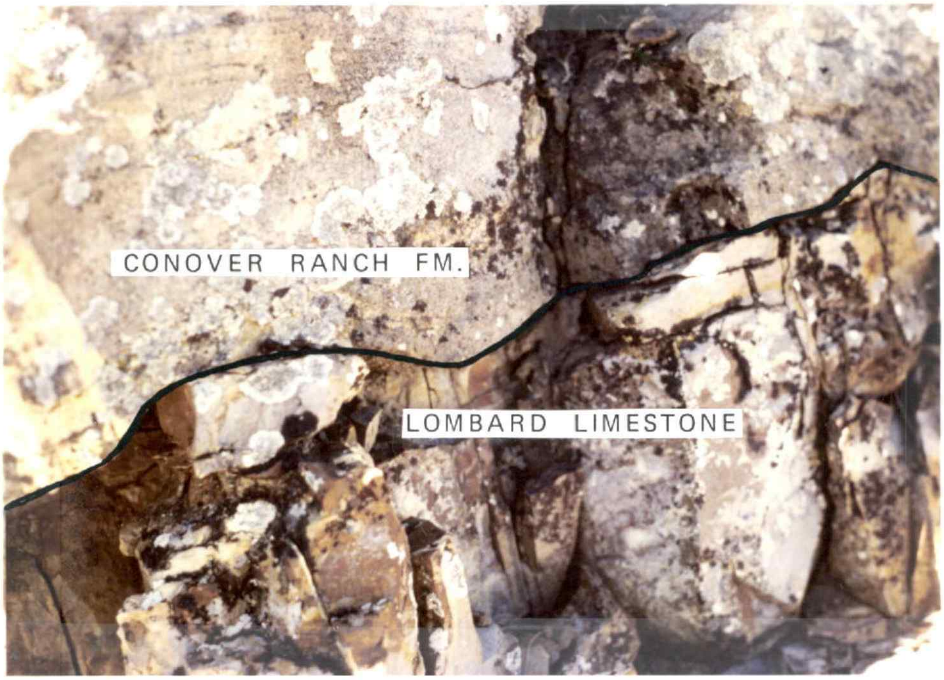


Figure 19. Close-up of contact between Conover Ranch Formation and Lombard Limestone at Sawtooth Mountain. Note truncation of upper most strata of Lombard Limestone against an undulating base of the Conover Ranch sandstone. Relief along the contact reaches 3 inches.

Formation could not be observed because of cover.

However, in the Blacktail Mountains at the Sheep Creek locality, an undulatory surface characterizes the lowermost limestone conglomerate of the Conover Ranch Formation. Beneath the limestone conglomerate there is a highly weathered zone which Maughan, of the U.S.G.S., believes represents a paleosol (personal communication, 1985).

Thus, based on the lithologies and contact characteristics observed at these two localities in the thesis area, the contact between the Lombard Limestone and Conover Ranch Formation appears to be unconformable. Perhaps though, the contact should be regarded as a diastem in the region as no paleontological evidence exists at this time to establish the duration of time between deposition of the two lithologic units.

LITHOLOGY

Shale-Siltstone Unit

The shale-siltstone unit dominates the Conover Ranch Formation and is recognized at all measured section sites within the thesis area. Despite this widespread occurrence, the unit rarely crops out, with most intervals consisting of grass-covered, red soil slopes. Where exposed, the unit consists of shales and platy to blocky siltstones which characteristically weather to a pale reddish (10R 6/2) color. At several localities, trenching revealed a lighter gray (N 6) color for some of the shales beneath a layer of red soil (figure 20). X-ray diffraction analysis reveals a shale mineralogy of mainly quartz, kaolinite, and hematite. Sporadically dispersed within the unit are ledges of very fine-grained sandstone. The best exposure of the shale-siltstone unit is at Sheep Creek in the Blacktail Mountains, although, in the view of the author, this section is anomalously thin and contains more fine-grained sandstone lenses than stratigraphically correlative sections measured in the Snowcrest Range.

The red color characteristic results from the presence of iron-oxides, mainly hematite. However, whether or not the hematite is detrital (Krynine, 1949) or post-depositional (Walker, 1967) in origin is debatable.

Quartz Arenite-Limestone Conglomerate Unit

The quartz arenite-limestone conglomerate unit of the Conover Ranch Formation crops out sporadically within the shale-siltstone unit and ranges in thickness from less than a foot to approximately 70 feet in the thesis area. Although the overall shape for the unit could not always be discerned in the field, a broad lenticular shape is speculated as the strata appear to pinch out laterally into the adjacent sedimentary units. The quartz arenite part of the unit tends to characterize the lowermost strata of the Conover Ranch Formation at all measured section sites except at Sheep Creek, where a limestone conglomerate crops out instead. However, despite this widespread basal occurrence, the unit generally does not crop out well above the more resistant

Figure 20. Trench revealing both a pale reddish (10R 6/2) and light gray (N 6) color for a section of shales through the Conover Ranch Formation. Photo taken at Sheep Creek locality, rock hammer for scale.

dark fissile limestones of the upper Lombard Limestone. An exception occurs on the northern flank of Sawtooth Mountain (sec. 9, T. 12 S., R. 5 W.) where both, the lenticular shape of the unit and the contact between the Lombard Limestone and Conover Ranch Formation, can be readily observed (figure 21).

At some localities in the thesis area, limestone conglomerates characterize the lowermost part of quartz arenite unit. Where exposed, the contact between the two lithologies varies from being gradational to sharp, with the sharp contacts appearing erosional (figure 22). However, the bulk of these erosional contacts merely represent localized scour-and-fill structures that developed within channelized sequences and, therefore, are limited in areal extent and regional significance. A schematic composite stratigraphic column of this unit would grade vertically from a basal limestone conglomerate into a well-developed trough cross-bedded quartz arenite sequence above (figure 23). In the field, a similar sequence to that shown in figure 23 is well exposed on the eastern flank of Sliderock Mountain in the Snowcrest Range (sec. 24, T. 10 S., R. 4 W.) where it reaches a thickness of 40 feet and can be traced laterally for nearly a quarter of a mile (figure 24).

In the field, the quartz arenite lithology is generally fine- to medium-grained, well-sorted, and characterized by numerous hematite-stained, trough cross-bed sets. The cross-bed sets tend to be normally graded with a few sets containing basal pebble lag layers. In addition, a vuggy porosity disrupts the cross-bedding at several localities. The vugs tend to be

Figure 21. View of the contact between the Conover Ranch Formation and Lombard Limestone at Sawtooth Mountain. Note the lenticular shape of the Conover Ranch sandstones above the Lombard Limestone.

Figure 22. View of the contact between the limestone conglomerate and quartz arenite units of the Conover Ranch Formation at Sawtooth Mountain. Note the sharp, apparently erosional nature of the contact. Rock hammer for scale.

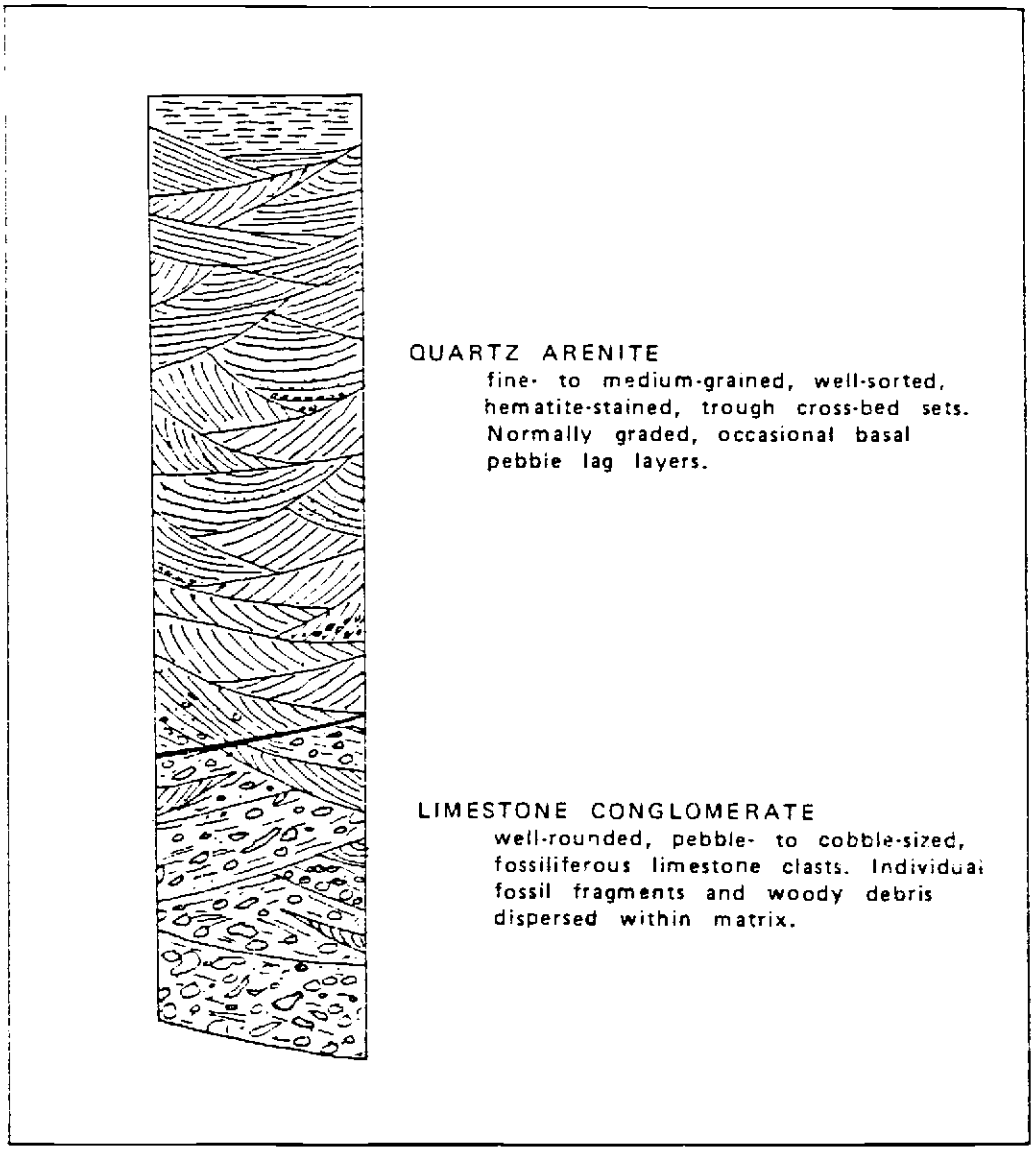


Figure 23. Schematic composite stratigraphic column through the quartz arenite-limestone conglomerate unit of the Conover Ranch Formation.

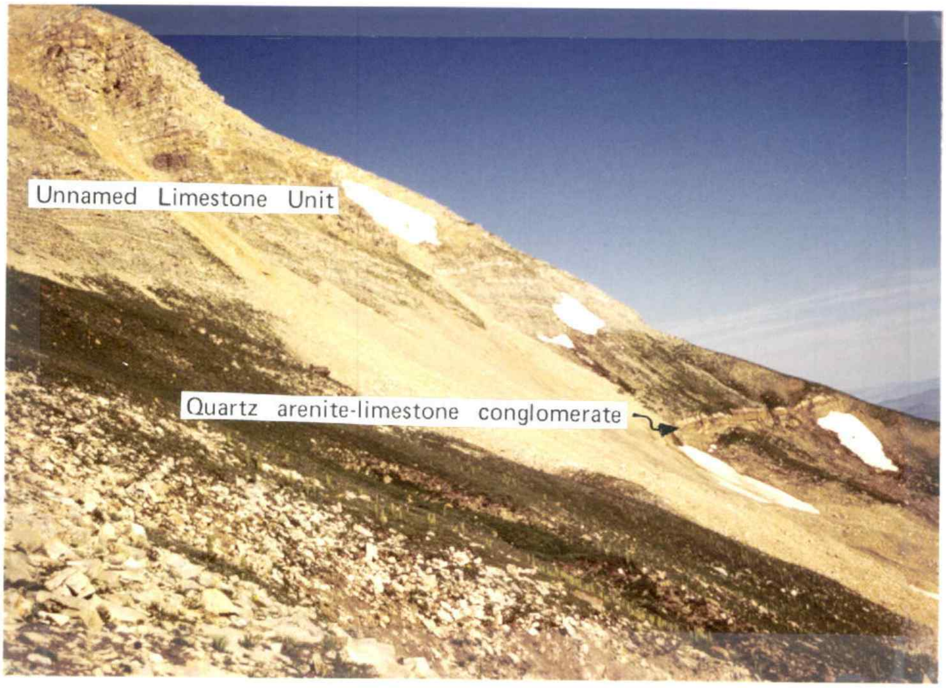


Figure 24. View of the quartz arenite-limestone conglomerate exposure on the eastern flank of Sliderock Mountain.

partially filled with sparry calcite crystals and are thought to represent fossil fragments that were dissolved and partially replaced during diagenetic processes. In the Snowcrest Range, the quartz arenite is usually calcite cemented but in the Blacktail Mountains and Gravelly Range, parts of the unit are dolomite cemented. The upper contact of the quartz arenite with the shale-siltstone unit is sharp and planar.

Petrographic study of the quartz arenite reveals that the framework consists almost wholly of well-sorted and well-rounded detrital quartz with a median grain size of approximately 0.25 mm. (fine sand). Many detrital quartz grains are characterized by syntaxial quartz overgrowths with a few grains displaying multiple generations of siliceous overgrowths (figure 25). Composing less than one percent of the framework grains are well-rounded accessory minerals which include tourmaline and zircon. Therefore, based on these parameters and following Folk's (1982) classification, the quartz arenite is considered to represent a texturally and compositionally mature sedimentary rock.

As previously mentioned, most quartz arenite is calcite cemented in the thesis area (figure 26). However, the percentage of calcite cement varies widely, from trace amounts to approximately 40% of the total rock volume. For most samples, however, the calcite cement composes between 5 - 15% of the total rock volume. Commonly, the calcite rhombs appear to be "eating into" the surrounding quartz overgrowths. From this physical relationship, one can presume that the syntaxial quartz overgrowths were precipitated prior to the precipitation of the calcite cement.

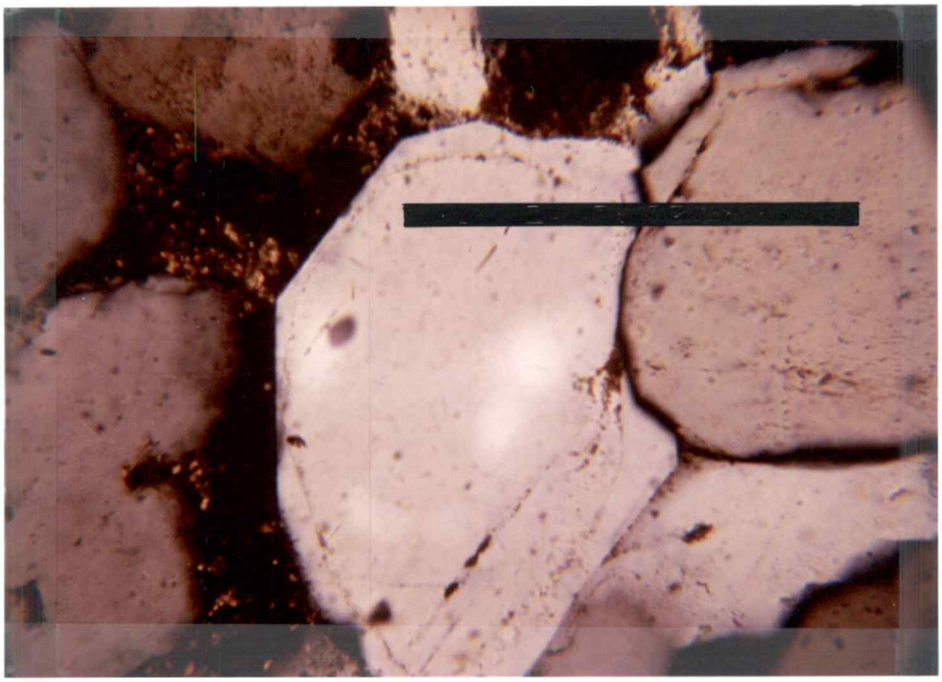


Figure 25. Photomicrograph of quartz arenite from the Conover Ranch Formation displaying syntaxial quartz overgrowths. Bar scale = 250 microns or 0.25 mm.

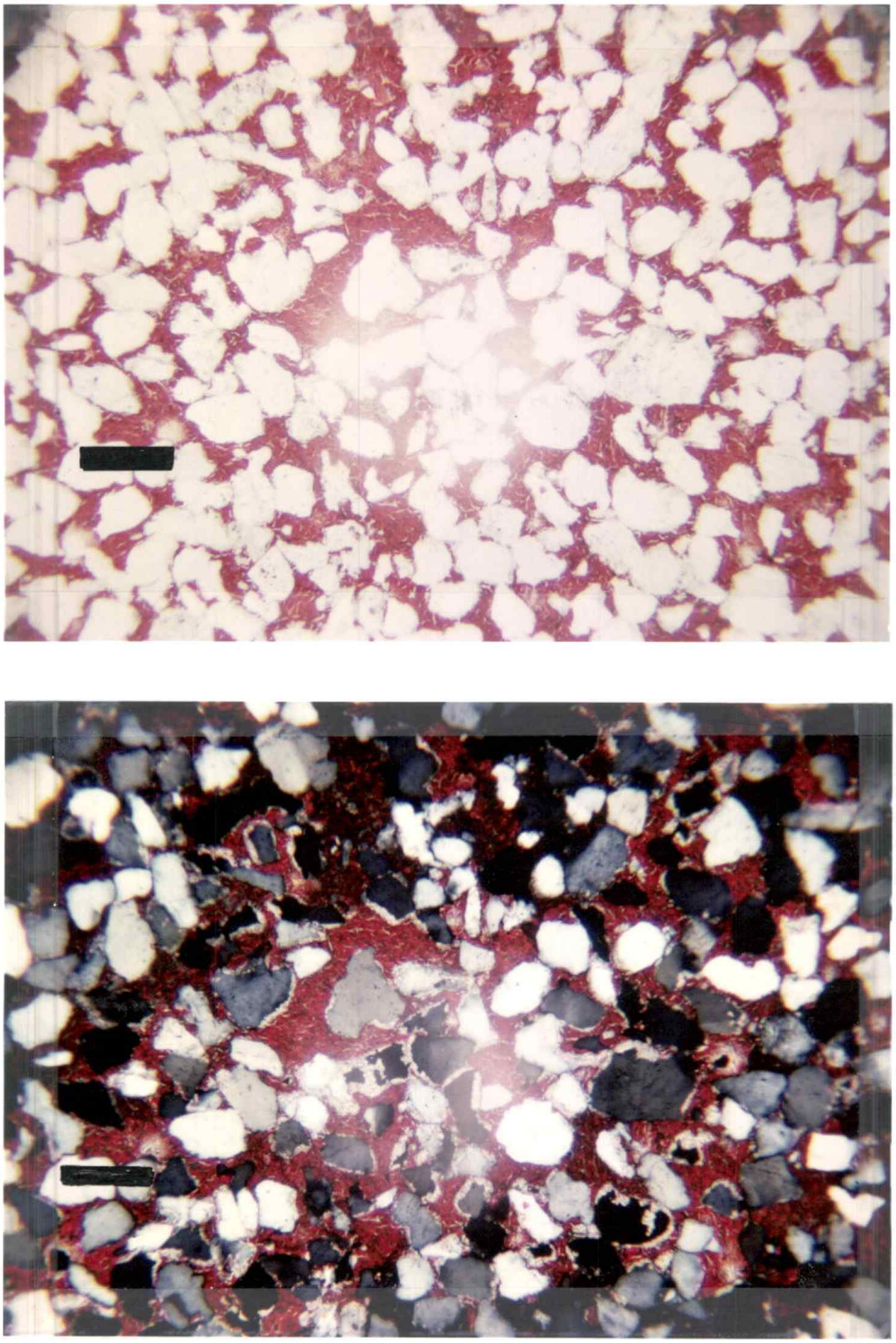


Figure 26. Photomicrographs of calcite-cemented quartz arenite from the Conover Ranch Formation. Calcite cement is highlighted in red from "Alizarin Red S" staining. A) uncrossed nicols (above), B) crossed nicols (below). Bar scale = 250 microns or 0.25 mm.

This cementation sequence is often observed in quartz arenites and is considered to be indicative of changing geochemical conditions associated with different stages of burial depth (Pettijohn et al., 1973). In some cases of extensive quartz overgrowths, the rock is completely cemented by authigenic quartz.

Locally in the Snowcrest Range, and predominantly at the Big Sheep Creek locality in the Tendoy Mountains, the quartz arenites are bound together by a combination of calcite and hematite cements. Petrographic study reveals that the hematite is invading and replacing the calcite cement along preferentially developed crystallographic cleavage traces (figure 27). Additionally, the quartz arenite sequences in the Tendoy Mountains tend to be slightly fossiliferous and consist of finer grained, more angular framework quartz grains than similar sequences exposed in the Snowcrest Range. Locally, the finer grained quartz arenites also display wave-rippled surfaces (figure 28). The overall less mature quartz arenite lithology at this locality suggests that sediments were derived from other sources in addition to the texturally mature clastic material shed through the Snowcrest trough.

The limestone conglomerate exposed beneath the quartz arenite at several localities consists primarily of well-rounded, pebble- to cobble-sized fossiliferous limestone clasts within a calcite-cemented quartz arenite matrix (figure 29). Also dispersed within the matrix are organic debris (wood fragments) and abraded fossils including ostracod, brachiopod, and pelecypod fragments. The unit is crudely cross-bedded with numerous cleaner sandstone

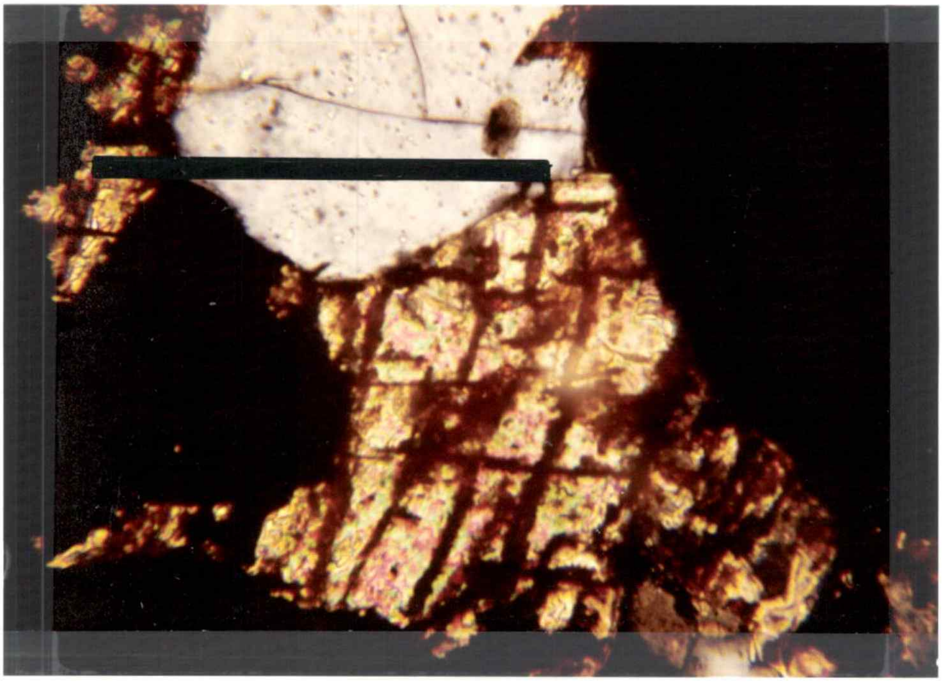


Figure 27. Photomicrograph of calcite-cemented quartz arenite from the Conover Ranch Formation displaying preferential replacement of the calcite cement by hematite along crystallographic cleavage traces. Bar scale = 250 microns or 0.25 mm.

Figure 28. Symmetrical wave-rippled surface, Conover Ranch quartz arenite, six inch ruler for scale. Photo taken at the Big Sheep Creek locality.

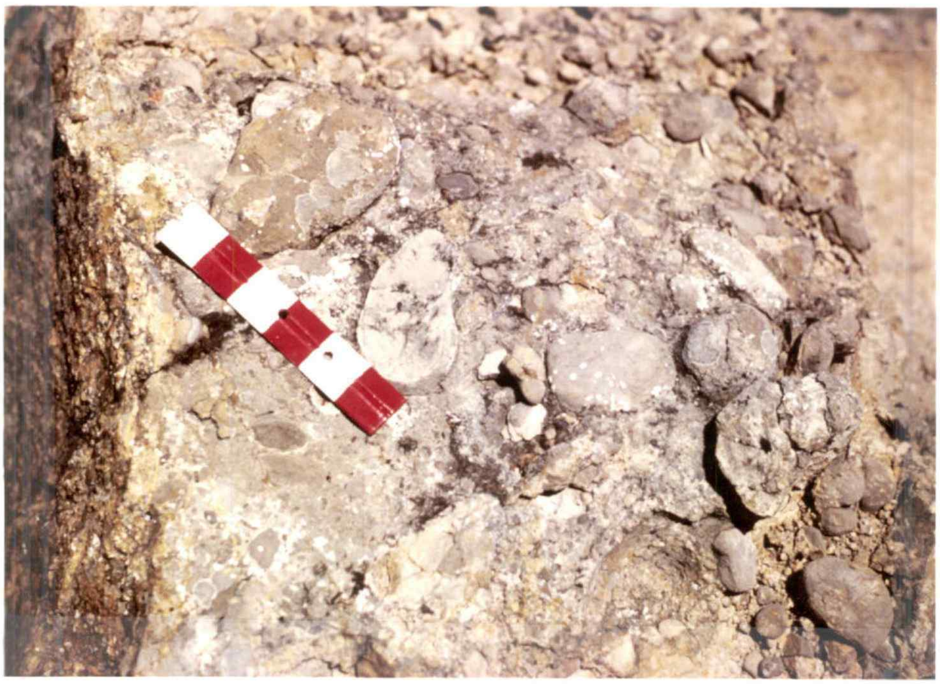


Figure 29. Photograph of the limestone conglomerate lithology within the Conover Ranch Formation, six inch ruler for scale. Photo taken at the Sheep Creek locality.

lenses dispersed within the conglomeratic lithology. The size, shape, and concentration of the detrital quartz grains within the matrix of the limestone conglomerate vary significantly throughout the thesis area from well-rounded, sand-sized grains at Hogback Mountain to angular, silt-sized grains at Sheep Creek.

At Sunset Peak, Siphonophylla sp., a genus indicative of Coral Zone V within the Lombard Limestone, was identified in several limestone clasts by W. J. Sando (personal communication, 1985) (figure 30). On the basis of this identification, it can be stated that at least some of the limestone clasts were derived locally from the underlying Lombard Limestone. It is also speculated that some of the limestone clasts represent Madison Group lithologies but, at this time, no paleontological evidence exists to substantiate this hypothesis.

In addition, petrographic study revealed that, in actuality, the quartz arenite-limestone conglomerate lithologies are transitional to one another. In most transitional assemblages, the framework grains consist of a mixture of subangular to rounded, sand- to very fine pebble-sized detrital quartz grains and fossiliferous limestone clasts. In some samples, abraded, rod-shaped, brachiopod fragments also are present (figure 31). In order to determine the compositional range of the quartz arenite-limestone conglomerate unit, point count analyses on 18 thin sections were performed. The results of these analyses are shown in figure 32 where detrital quartz grains and abraded limestone clasts constitute the end members in a simple binary classification scheme. From this classification, three distinct

Figure 30. Photograph of Siphonophylla sp. within the limestone conglomerate unit of the Conover Ranch Formation. Sample collected at the Sunset Peak locality. Scale: one inch increments in background.

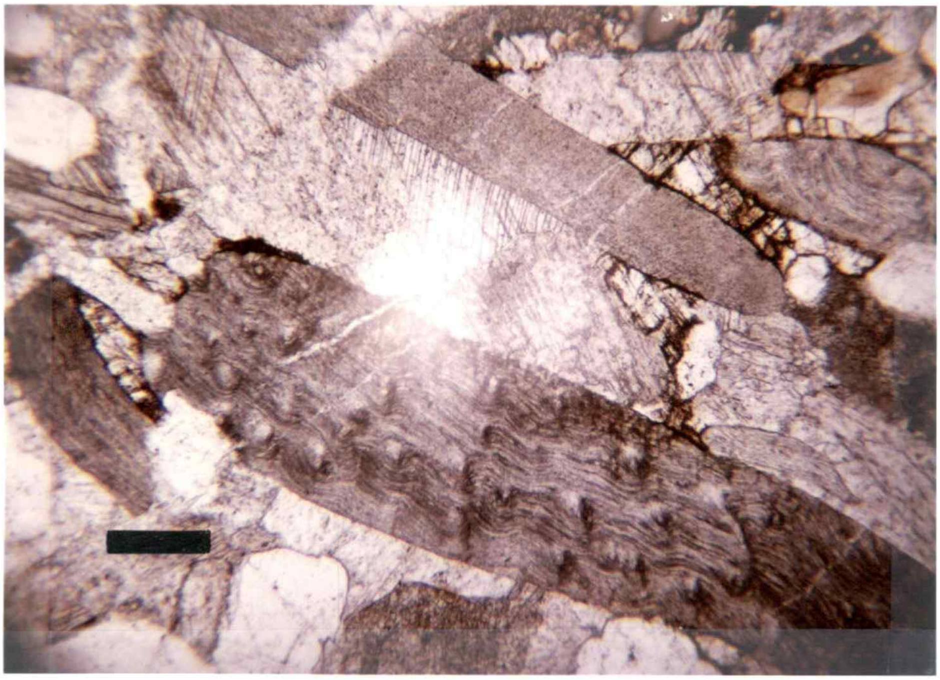


Figure 31. Photomicrograph of limestone conglomerate unit from the Conover Ranch Formation. Note tabular brachiopod fragments. Bar scale = 250 microns or 0.25 mm.

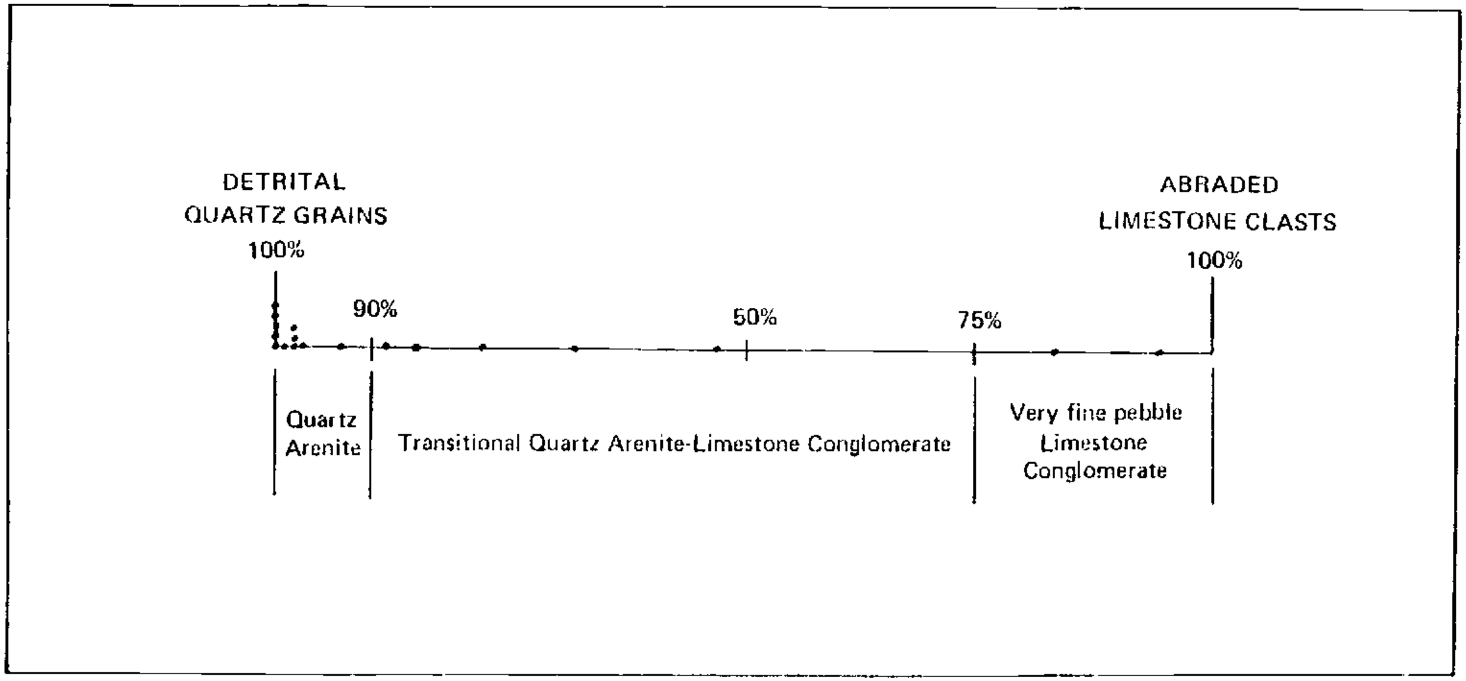


Figure 32. Compositional plot of 18 quartz arenite-limestone conglomerate lithologies. Solid dots (•) represent individual samples.

lithologies can be recognized: one, a quartz arenite; two, a very fine pebble limestone conglomerate; and three, a transitional quartz arenite-limestone conglomerate assemblage. If one assumes that the very fine pebble limestone conglomerate represents a "scaled-down" version of the pebble- to cobble-sized limestone conglomerate, then a complete transitional assemblage of the quartz arenite-limestone conglomerate unit is supported by this analysis.

Additionally, the majority of the very fine pebble limestone conglomerates tend to be completely cemented by sparry calcite crystals. Thus, according to Dunham's 1962 carbonate classification scheme, these rocks would be classified as grainstones as they lack mud matrix and are in grain support. The implications of such a lithologic assemblage are that either the rock was deposited in a mud-free environment or that the muds were preferentially removed by currents in the depositional environment. Based on the overall muddy nature of the Conover Ranch Formation in the thesis area, the latter origin is favored.

DEPOSITIONAL ENVIRONMENT

The lithologies and sedimentary structures of the Conover Ranch Formation within the thesis area suggest deposition in a shallow, low-energy, marginal marine environment. However, slight differences in lithologies and sedimentary structures within the formation between the Blacktail Mountains, Tendoy Mountains, and Snowcrest Range also suggest that slightly different depositional environments characterized each of these regions during latest Mississippian time. Nevertheless, the Conover Ranch Formation is considered to represent a transgressive, deepening-upwards sequence throughout the thesis area. The fine-grained clastic material dominating the formation was derived from a complex fluvial system which drained through Montana from east to west via the Big Snowy and Snowcrest troughs. Evidence to support this Late Mississippian-Early Pennsylvanian fluvial system has been documented by Mundt (1956a), Maughan and Roberts (1967), Harris (1972), Brewster (1984), and Maughan (1984), just to mention a few workers. In addition, it should be noted that this fluvial system was dominated by silt- and clay-sized particles in the vicinity of the Snowcrest trough and only on rare occasions were detrital sand-sized grains shed into this region. The muddy bedload characteristic of the fluvial system has also been recognized by Brewster (1984), who working in the Lombard arch area, states that a "lack of similar sand bodies at this locality suggests.....a river that was suppling very little sand".

In the Snowcrest Range, the shale-siltstone unit of the Conover Ranch Formation was probably deposited in a shallow water, very low energy tidal to subtidal environment. The general absence of fossils within the unit suggests that the environmental conditions were inhospitable towards most normal marine macrofossil communities. Despite an absence of fossils, a subaqueous environment is favored as no subaerial exposure evidence was found within the unit in the thesis area. However, to the northeast in the vicinity of the Lombard arch, Brewster (1984) cites evidence for localized paleosol development in a stratigraphically correlative shale-siltstone sequence. Yet, when considering the Late Mississippian-Early Pennsylvanian paleogeography of this region, one might expect isolated paleosols within the stratigraphic sequence as the area was located on the tectonically uplifted southwestern limb of the Lombard arch.

In contrast to the shale-siltstone unit, the quartz arenite-limestone conglomerate unit in the Snowcrest Range was deposited in a higher energy depositional environment. Based on sedimentary structures, the presence of abraded fossil fragments within the framework and matrix, and the overall lenticular shape of the unit in the field, the quartz arenite-limestone conglomerate unit is considered to represent a tidal channel deposit. A similar set of criteria have been described by Clifton (1982) for modern tidal channels. In the thesis area, the tidal channels merely reflect an offshore extension of the fluvial system previously described. The abraded fossil fragments within the framework and matrix probably represent bioclastic debris derived from more normal marine environments to the west that were "flushed up" the tidal channels during stronger periods of flood tide flow. Owing to the very low preservation potential of carbonate material during bedload transport, the limestone clasts are considered to have been locally derived, whereas the texturally mature detrital quartz grains were derived from more distant sources, probably the Canadian Shield or Transcontinental arch. In similar quartz arenite sequences within the Tyler Formation of central Montana, the source for the detrital quartz grains is also thought to have been the Canadian Shield (Ballard, 1961; Maughan, 1984).

The source for the limestone clasts is more problematic. It is speculated that they were derived from subaerially exposed carbonate rocks along fault scarps developed along the northwestern margin of the Beartooth platform. Another possible source area might have been to the northwest in the vicinity of the present-day Blacktail Mountains. As discussed in the lithology section, the limestone clasts consist of fragments from the Lombard limestone and probably from the Madison Group as well. It is speculated that during times of flooding or cloud bursts, the limestone clasts were eroded from the local highlands and shed into the preexisting fluvial drainage system. Depending on the intensity of flooding, the limestone clasts were funneled out into the Snowcrest trough via tidal channels for deposition. As flood conditions waned, the limestone clasts settled out first as a basal lag followed by finer grained sediments above. As the environment returned to more normal conditions, the finer grained sediments deposited during flood conditions in the tidal channels were selectively winnowed out by ebb and flood tide currents. Occasionally during some flood events, the limestone clasts were not restricted to channelized deposits and consequently spread out as thin debris aprons across the shallow water mudflat environment. Locally on "highs" within the depositional environments, the limestone clasts were reduced in size in response to more agitated water condition to form grainstone assemblages.

To the southwest in the Tendoy Mountains, the sedimentary structures and fossil assemblages within the quartz arenite unit suggest deposition farther out on the tidal mudflat closer to a normal marine environment. As previously discussed, the variety of detrital quartz grains characterizing the unit in the Tendoys probably reflects sediment input from local sources in addition to the clastic sediments draining through the Snowcrest trough. A more proximal marine setting is based on the increasing percentage of normal marine fauna within the quartz arenite unit.

In the Blacktail Mountains, the Conover Ranch Formation is only 118 feet thick and is characterized by coarser grained clastic sequences than elsewhere in the thesis area. The lower 28 feet of the formation are dominated by ledges of limestone conglomerates and grainstone lithologies, both of which are indicative of more turbulent water conditions. It is speculated that this sequence represents a shallow nearshore deposit with the limestone clasts being derived locally, perhaps from a nearby Big Snowy sea cliff. The middle 60 feet of the formation consist primarily of finer grained siltstones and shales interbedded with isolated thin limestone conglomerate lenses. This lithologic sequence is interpreted as representing deeper water deposits which probably correlate with the upper shale sequence in the Snowcrest Range. The remaining 30 feet of the stratigraphic interval, which consists of limestone and fine-grained sandstone sequences, are only placed within the Conover Ranch Formation in the thesis area to conform with the newly proposed nomenclature of the region by Wardlaw and Pecora (1985). However, it is speculated that this interval may represent a northwestern extension of the unnamed limestone unit recognized in the Snowcrest Range (see plate 1). Regardless of the nomenclatural assignment, the sequence is interpreted as being deposited in a littoral environment which concurrently supported both carbonate and clastic sedimentation.

The thinness of the Conover Ranch Formation in the Blacktail Mountains indicates that the region, during latest Mississippian time, was relatively stable tectonically in comparision to the fault-bounded, subsiding Snowcrest trough. If anything, the region might have acted as a "hinge-line" during the downdropping of the Snowcrest trough to the southeast.

FOSSILS AND AGE

The Conover Ranch Formation within the thesis area has a paucity of fossils. The age of the formation has been assigned to the late Chesterian (Mamet Foraminiferal Zone 19 & Sando and Bamber Coral Zone VI) by Wardlaw and Pecora (1985). To the northeast, the formation becomes progressively younger and incorporates the Mississippian-Pennsylvanian boundary in the Jefferson Canyon River area (Wardlaw and Pecora, 1985).

The only fauna recovered from the Conover Ranch Formation were two specimens of Siphonophyllia sp., a late Chesterian coral (Dutro et al., 1984; Sando and Bamber, 1984; and Sando, personal communication, 1985). However, the corals are incorporated within limestone clasts that are considered to have been derived from the underlying Lombard Limestone. Therefore, they are not indicative of an age for the Conover Ranch Formation, but imply that the formation is of a post-Chesterian age. However, based on a latest Chesterian age assignment for brachiopods collected within the overlying unnamed limestone unit by J. Thomas Dutro, Jr. (personal communication, 1985), the Conover Ranch Formation in the thesis area can be assigned to the late Chesterian.

LIMESTONE UNIT (unnamed)

The limestone unit is well-exposed along the arcuate trend of the Snowcrest Range in the thesis area, especially between Sawtooth and Sliderock Mountains. Additionally, a southwestern extension of the unit crops out moderately well at the Big Sheep Creek locality in the Tendoy Mountains. During a brief reconnaissance of the Gravelly Range near the headwaters of the middle fork of Warm Springs Creek, the limestone unit was not recognized. However, other studies within the Gravelly Range (Mann, 1950; Hadley, 1960) have reported a thin limestone sequence between a red shale-sandstone interval, presumed to be the Conover Ranch Formation, and the Quadrant Formation. In a similar situation in the Blacktail Mountains, a thin limestone unit interbedded with red shales and siltstones crops out in the upper part of the Conover Ranch Formation below the Quadrant Formation. The regional distribution and thicknesses of the limestone unit in the thesis area are shown on plate 1.

In the Snowcrest Range, the limestone unit ranges in thickness from 250 - 371 feet between Sawtooth and Sliderock Mountains. The unit is characterized by steep ledge-forming and cliff-forming intervals that consist of thin- to medium-bedded limestones interbedded with calcareous shales (figure 33). The lower contact is planar with the underlying Conover Ranch Formation and is considered conformable. The upper contact of the unnamed limestone unit is also considered conformable as its contact is gradational with the lower dolomitic interval of the Quadrant Formation.

LITHOLOGY

The limestone unit in the thesis area consists of medium-bedded light olive gray wackestones and micritic mudstones, thinly bedded yellowish gray brachiopod packstones, light brownish gray calcareous shales, and dark gray organic-rich mudstones. Additionally, a bryozoan packstone interval near the top of the limestone unit is recognized at two separate localities in the Snowcrest Range. At some measured section sites, localized faulting has brecciated parts of the limestone unit resulting in recrystallization of the unit.

Medium-bedded wackestones dominate the limestone unit and range in color from light olive gray (5Y 6/1) to light brownish gray (5YR 6/1) on fresh surfaces to lighter shades of gray (N 6 - N 8) on weathered surfaces. In the field, the wackestone intervals grade both vertically and laterally into packstones and mudstones. Interrupting the bedded wackestone sequences are localized, encrinite intervals which probably represent storm- or flood-induced scour-and-fill deposits. Throughout the wackestone

Figure 33. View of medium-bedded limestones characteristic of the unnamed limestone unit; rock hammer for scale. Photo taken at Sliderock Mountain.

sequence, darker gray (N 3 - N 4) to brownish gray (5Y 4/1) chert nodules (2"x 3") and stringers (1"x 6") occur concentrated in zones oriented parallel to bedding (figure 34).

The wackestones are composed of micritic muds and bioclastic debris which includes brachiopod, crinoid, ostracod, bryozoa, and locally pelecypod and foraminifera fragments. Many of the fossil fragments display micritized rims indicative of boring processes within the skeletal material by filamentous blue green algae in the carbonate environment (Bathurst, 1975). The overall association of fragmented fossil assemblages within a micritic matrix is suggestive of textural inversion, whereby abraded fossil fragments from higher energy zones were transported and deposited in a quieter water, muddy environment. Locally though, whole, articulated ostracod carapaces are preserved and characterized by interior chambers filled with sparry calcite crystals (figure 35). In more spar-rich wackestones, the "poorly washed biosparites" of Folk (1962), crinoid plates display optically continuous calcite overgrowths (figure 36).

While the majority of fossil fragments, excluding pelecypods, retain the original internal shell structures and compositions, localized silicification has occurred, particularly within bryozoa and brachiopod fragments (figure 37). Despite this replacement process, the internal shell structures of many brachiopod fragments are preserved as "ghost" outlines within the siliceous matrix.

At one locality in the thesis area (Spur Mountain, bed number 16), 1/2 - 1 inch oncolite stuctures are dispersed within a

Figure 34. Photograph of dark gray (N 3) chert stringers within light olive gray (5Y 6/1) limestone of the unnamed limestone unit, six inch ruler for scale. Photo taken at Sawtooth Mountain.

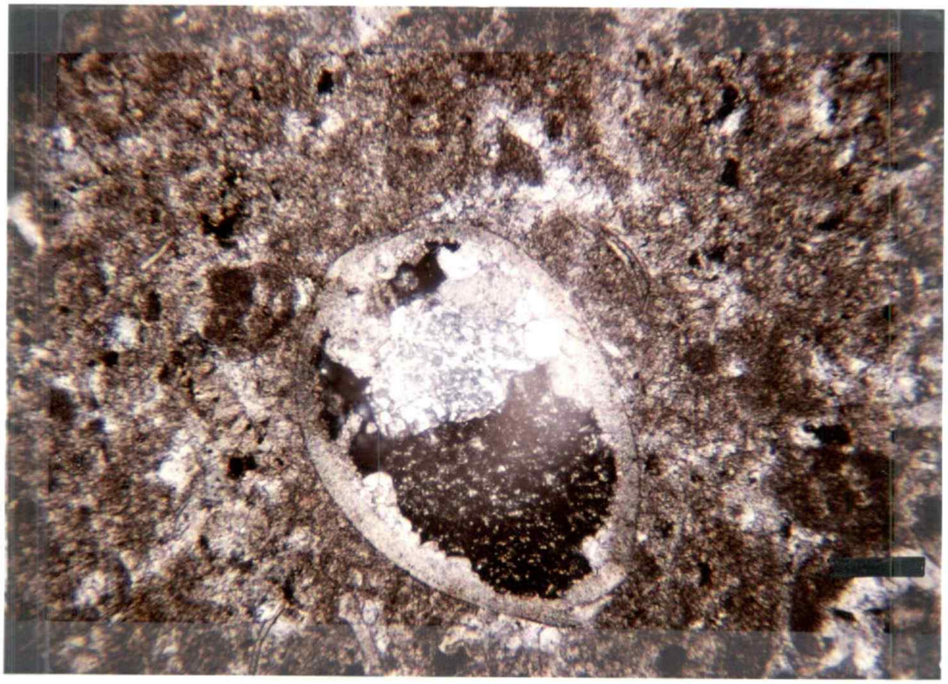


Figure 35. Photomicrograph of an articulated ostracod carapace. Note the spar-filled ostracod chamber within a dirty, micritic limestone matrix. Bar scale = 250 microns or 0.25 mm.

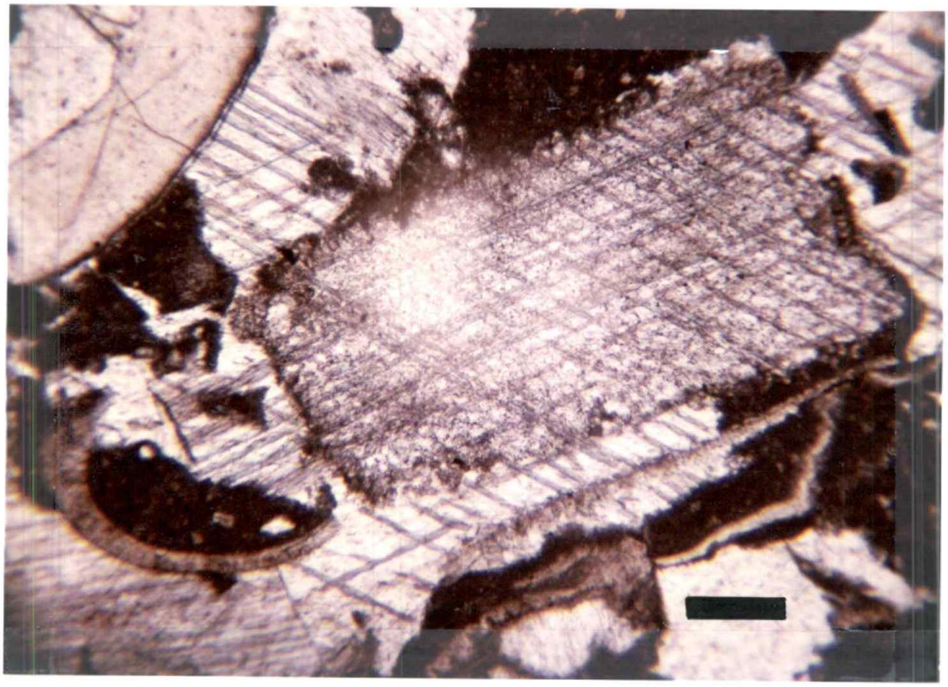
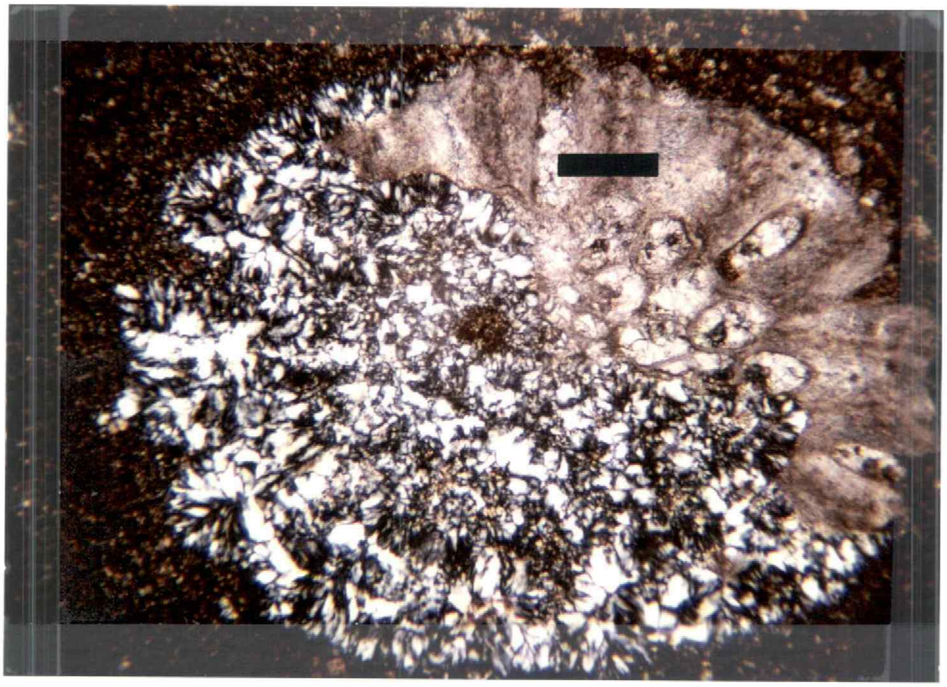


Figure 36. Photomicrograph displaying an optically continuous calcite overgrowth around a crinoid plate. Bar scale = 250 microns or 0.25 mm.



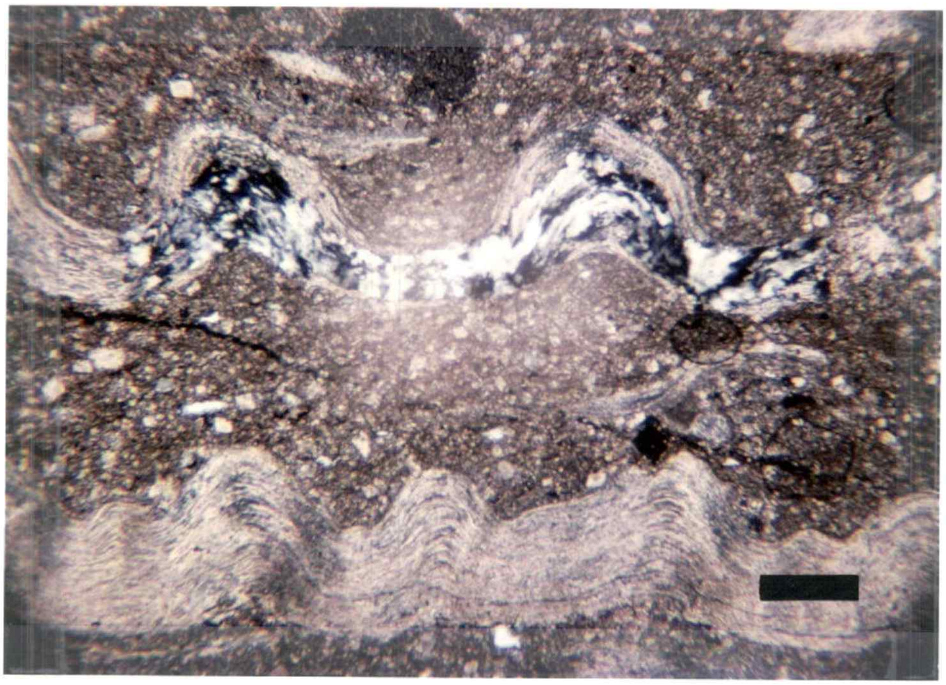


Figure 37. Photomicrographs of fossil fragments which have been partially silicified; A) bryozoan (above), B) brachiopod (below). Bar scale = 250 microns or 0.25 mm.

wackestone lithology. Despite soft sediment deformation, the algally laminated structures characteristic of oncolites can be distinguished in thin section analysis. Due to the presence of the oncolites, one can assume that the depositional environment of this wackestone was in close proximity to an algally laminated intertidal region.

At some localities in the wackestone sequence, the surfaces of the beds are mottled. This peculiar textural feature is thought to have been caused by bioturbation of the carbonate muds by burrowing benthonic organisms. Thus, it is speculated that a combination of mechanical abrasion, micritization, and bioturbation processes caused the skeletal material in the carbonate environment to be fragmented.

The thinly bedded brachiopod packstones are typically yellowish gray (5Y 8/1) and crop out as a series of thin, platy ledges in the limestone unit. Between individual packstone ledges, sparsely fossiliferous shaly intervals predominate. The brachiopods within the packstone assemblages generally consist of well-preserved, disarticulated valves (figure 38) which are densely concentrated, one on top of another, in a convex up orientation that parallels the direction of bedding. When viewed in cross-section, normal to bedding, the packstones are characterized by undulatoric laminations stemming from the dense, parallel arrangement of brachiopod valves. Other associated bioclastic materials include fragmented ostracod carapaces and crinoid debris.

As mentioned, two bryozoan packstone intervals at separate

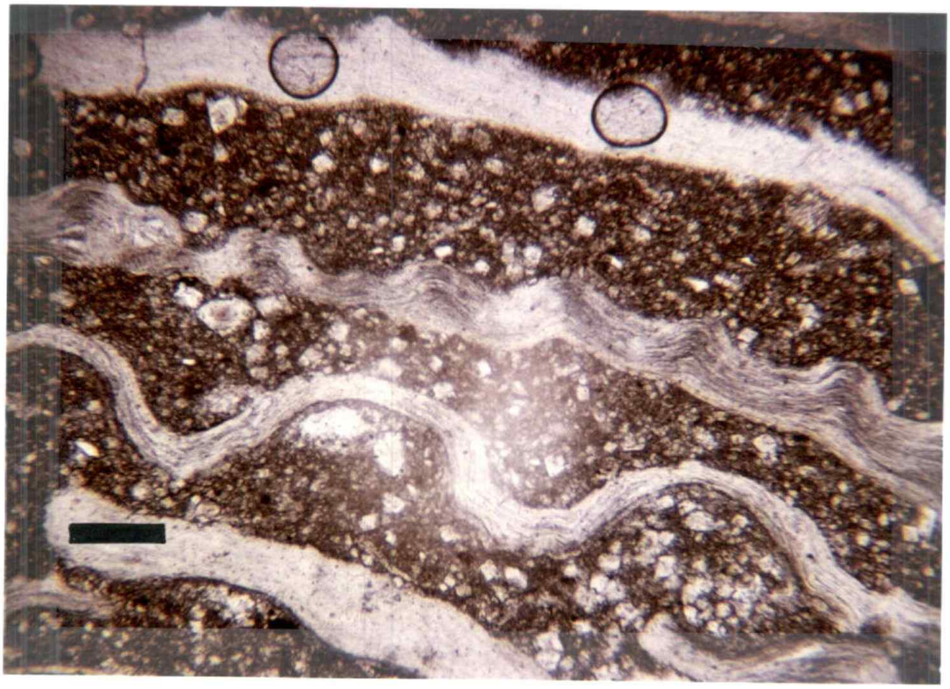


Figure 38. Photomicrograph of brachiopod packstone. Note parallel arrangement of brachiopod valves and small, rhombdohedral dolomite crystals within matrix. Bar scale = 250 microns or 0.25 mm.

localities in the Snowcrest Range (Sawtooth Mountain, bed number 30 and Hogback Mountain, bed number 37) were recognized in the upper part of the limestone unit. At both localities, the bryozoan packstones compose only two to three feet of stratigraphic section and appear to be lenticular in shape grading laterally and vertically into brachiopod packstones and wackstones. The bryozoans are in growth position and consist of tightly intertwinned branching varieties of Trepostomes and Cystoporids (Sando, personal communication, 1985). Thus, on the basis of the preceding evidence, the bryozoan packestones are considered to represent small colonial patch reefs within a littoral carbonate environment.

The calcareous shales within the limestone unit generally do not crop out well between the more resistant wackestones and packstones, but where exposed, they are characterized by light brownish gray colors (5YR 6/1 to 5Y 8/1). Dispersed at places within the shales are disarticulated brachiopod valves and crinoid debris. Locally, the shales grade vertically into bedded wackestones and packstones.

The micritic mudstone beds within the limestone unit are also gradational into wackestones. As a result of bioturbation, the micrite beds are nearly homogeneous in fabric, only being disrupted by a few well-abraded, micritized fossil fragments. Locally, small (2"x 3") dark gray chert nodules occur within the interval.

The dark gray (N 3 - N 4), organic-rich mudstone beds crop out sporadically within the limestone unit and vary in habit from thinly bedded, platy sequences to more massive, blocky exposures. In all instances, the lithology is recognized, not only on color, but also by the presence of a strong fetid odor from freshly broken surfaces. The presence of organic-rich rocks within the limestone unit implies that local anoxic conditions must have existed within the carbonate environment. In light of the organic characteristics of the mudstone, 10 samples were collected from five different measured section localities in the Snowcrest Range for hydrocarbon source rock analysis, the results of which are discussed in a later section of the thesis.

DEPOSITIONAL ENVIRONMENT

The fossils, lithologies, and sedimentary structures of the limestone unit within the thesis area suggest deposition in a shallow water carbonate shelf environment. According to Wilson's (1975) facies classification of carbonate environments, the limestone unit would indicate middle to inner shelf settings (facies #7 and #8). Evidence to support this interpretation are: one, the abundance of "normal" marine faunas; two, the predominance of wackestone and packstone carbonate lithologies associated with muddy intervals and isolated small patch reefs; and three, the gradational nature of the carbonate lithologies within the stratigraphic sequence. Paleoecological implications of a middle shelf environment include normal salinities, water depths near or within the photic zone, water temperatures between 10° - 30° C., and bottom conditions that are well-oxygenated and generally below normal wave base, but above storm wave base. However, as previously mentioned, the organic-rich mudstones within the limestone unit indicate that localized anoxic conditions, characterized by limited water circulation, must also have coexisted in the carbonate environment. In addition, environmental settings on the shelf were periodically closer to algally laminated intertidal regions based on the presence of oncolites. The isolated bryozoan patch reefs are speculated to have developed on small mud mounds where the water circulation was baffled by the branching bryozoan communities. Also, the occurrence of the bryozoan patch reefs in only the upper part of the limestone unit is considered to coincide with the onset of shallower water clastic sedimentation characteristic of the lower Quadrant Formation in the Snowcrest trough. Thus, the limestone unit in the thesis area is considered to represent a shallowing-upwards sequence. It is also believed that the unit records, in the lower limestone strata, a post-Lombard time of maximum water depth in the Snowcrest trough.

The thin limestone interval noted in the Blacktail Mountains is considered to represent a northwestward extension of the limestone unit recognized throughout the Snowcrest Range. However, the clastic characteristics of the limestone unit at this locality, in comparision to the sequences within the Snowcrest Range, suggest that the depositional environment was closer to a land source. Accordingly, a nearshore depositional setting for the limestone unit in the Blacktail Mountains would tie in nicely with the environmental setting speculated for the underlying Conover Ranch Formation in the region as well.

The thin limestone sequences described by other workers in the Gravelly Range (Mann, 1950; Hadley, 1960), presumably represent analogous depositional settings that existed on the northwestern margin of the Beartooth platform during latest Mississippian time.

Transitional Upper Contact

In the uppermost part of the limestone unit, the limestones are interbedded with dolostones and dolomite-cemented quartz arenite sequences of the lower Quadrant Formation (figure 39). As a consequence, the upper contact is arbitrarily placed where a predominantly limestone lithology gives way to dolomitic lithology. Because of this practice, the upper contact is probably placed at slightly different stratigraphic positions at each locality in the thesis area, but this difference is probably negligible when considered on a regional scale.

Locally, scour-and-fill structures characterize the contacts between dolomite-cemented quartz arenites and limestones in the transistional sequence. Also, the percentage of fine-grained detrital quartz in the uppermost limestones progressively increases towards the base of the Quadrant Formation. The detrital quartz grains are typically silt-sized, angular to subangular, and concentrated in thin layers within the limestones.

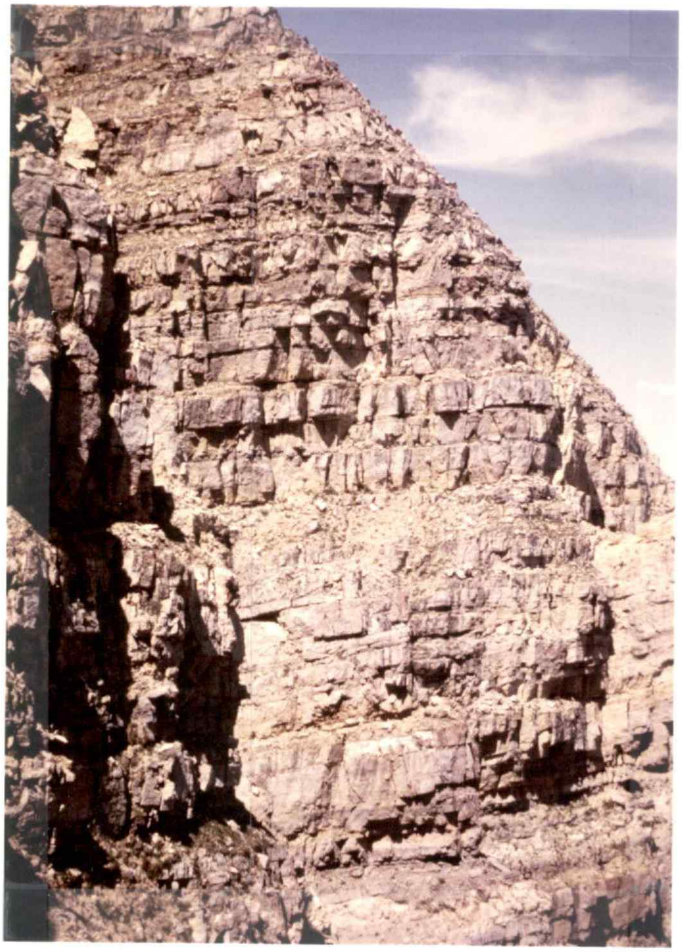


Figure 39. View of transitional contact between the unnamed limestone unit and the lower dolomitic part of the Quadrant Formation at Sliderock Mountain.

FOSSILS AND AGE

The limestone unit of the thesis area is generally fossiliferous, with brachiopods, crinoids, bryozoas, ostracods, pelecypods, and forams. However, only the brachiopods are utilized in this thesis for age dating purposes. The following brachiopods were identified and assigned a latest Chesterian age by J. Thomas Dutro, Jr. (personal communication, 1985): Orthotetes kaskaskiensis bransonorum Gordon, Composita cf. C. poposiensis Gordon, Anthracospirifer welleri lincolnensis Gordon, Anthracospirifera aff. A. occiduus Sadlick, Cleiothyridina? sp., and Orbiculoidea cf. O. wyomingensis Branson and Greger. Dutro also suggested that these particular brachiopods bore an affinity with brachiopod collections documented by Gordon (1975) from latest Chesterian strata (Foram Zone 19 and highest Foram Zone 18) in western Wyoming. Thus, the limestone unit in the thesis area is considered to be of latest Chesterian age.

QUADRANT FORMATION

The Quadrant Formation is well exposed in the thesis area. The Quadrant tends to be very resistant to weathering and crops out as either cliff- or dip slope-forming intervals that "hold up" the core of late Paleozoic rocks throughout the Snowcrest Range (figure 40). Below the cliff-forming intervals, large Quadrant blocks commonly form extensive talus slopes which obscure the underlying formations. The formation is primarily composed of an

Figure 40. View of the Snowcrest Range as seen from the summit of Sliderock Mountain. Mountain peaks, from left to right, are Sawtooth Mountain, Sunset Peak, Olsen Peak, and Hogback Mountain. Each mountain peak is held up by the Quadrant Formation.

upper calcite- or silica-cemented quartz arenite sequence above a lower sequence of alternating dolomite-cemented quartz arenites and dolostones. In this thesis, only the lower dolomitic interval is described.

The dolomitic interval is recognized at all localities in the thesis area except at Sheep Creek in the Blacktail Mountains and at Red Rock River in the southern Snowcrest Range. At the latter locality, however, the "absence" of the interval is probably due to the section being poorly exposed. Despite an emphasis on the lower dolomitic interval, several complete stratigraphic sections were measured through the Quadrant Formation for thickness data in the Snowcrest Range. However, it should be noted that measured sections of the Quadrant Formation in the northern Snowcrest Range at Snowcrest Mountain and Ruby Gap, are anomalously thin because of structural deformation. The regional distribution and partial thicknesses of the Quadrant Formation in the thesis area are shown on plate 1.

LITHOLOGY

The lower dolomitic interval of the Quadrant Formation consists of an alternating sequence of thinly to very thickly bedded dolomite-cemented quartz arenites and dolostones. The contacts between the two rock types are generally sharp although local scour-and-fill structures characterize the lower beds of the quartz arenites.

The dolomite-cemented quartz arenites are fine-grained, well-sorted, and locally trough cross-bedded. Some surfaces in this unit display sinuous, symmetrical 1 inch ripple marks (figure 41). Where cross-bedding is not apparent, the quartz arenites appear massive, probably as a result of bioturbation. Petrographically, the fine-grained framework is composed almost entirely of monocrystalline, well-sorted, and subrounded to rounded detrital quartz grains (figure 42). Locally, a distinct bimodal grain distribution is noted (figure 43). Around many of the detrital quartz grains, syntaxial quartz overgrowths have developed (figure 44). Composing less than 1% of the framework grains are well-rounded accessory minerals which include zircon and tourmaline. On the basis of textural and compositional parameters, the dolomite-cemented quartz arenitse would be classified as a mature sedimentary rocks (Folk, 1982). The dolomite cement is generally finely crystalline and has precipitated as distinct, rhombdohedral crystals in the pore spaces between the framework grains.

The dolostone intervals are considered to represent completely dolomitized limestones. The textures of the dolostone range from a coarse-grained, sparkly variety to a fine-grained, dolomicrite assemblage. Locally, poorly preserved fossil fragments are present. On the bottom of some beds, anastomosing burrow tubes stand out in relief. Petrographically, the dolostones are associated with varying amounts of silt- to sand-sized detrital quartz grains; in some samples these approach a sandy dolostone.

The dolomite in both lithologies is considered to be a post-depositional diagenetic product. Of the existing dolomitiza-

Figure 41. Photograph of snubbed ripple marks within the Quadrant Formation. Six inch ruler for scale.

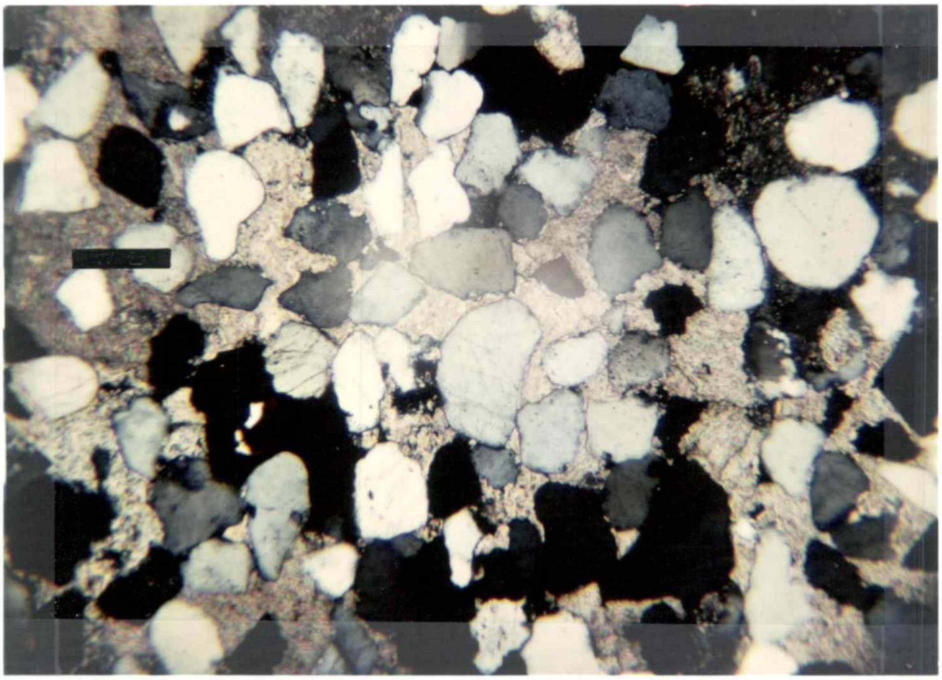


Figure 42. Photomicrograph of dolomite-cemented quartz arenite from the Quadrant Formation. Bar scale = 250 microns or 0.25 mm.

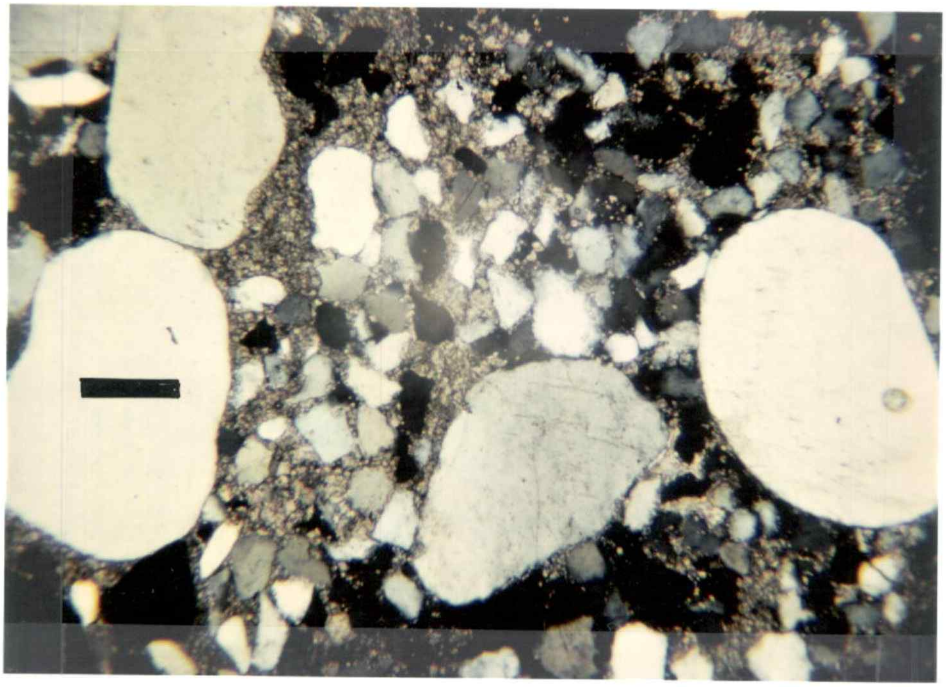


Figure 43. Photomicrograph of dolomite-cemented quartz arenite from the Quadrant Formation displaying a distinct bimodal grain size distribution. Note the well-rounded nature of the larger quartz grains compared to the subangular smaller quartz grains. Bar scale = 250 microns or 0.25 mm.

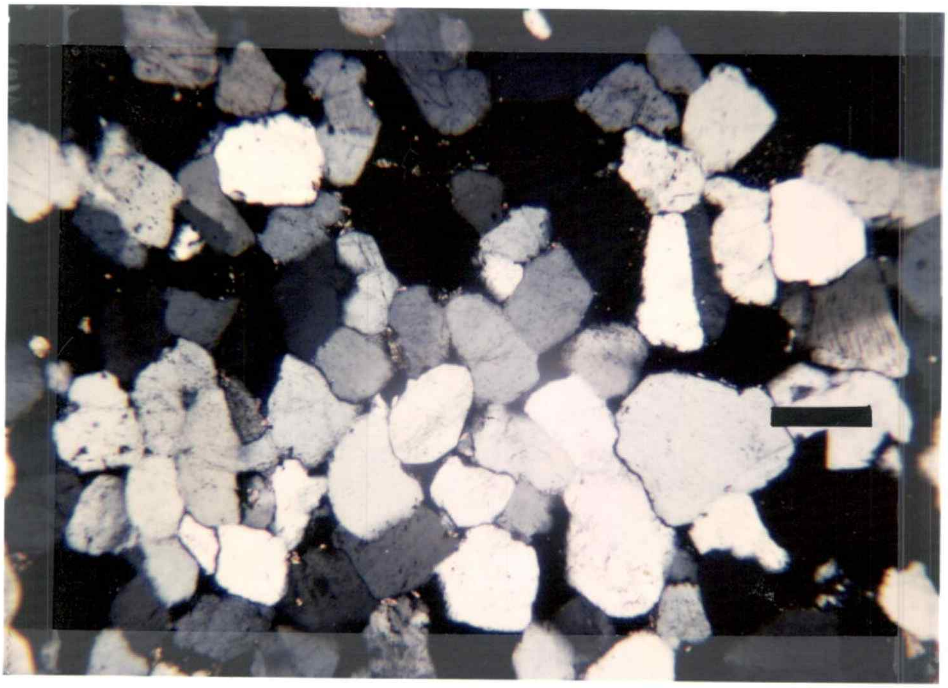


Figure 44. Photomicrograph of syntaxial quartz overgrowths within a quartz arenite from the Quadrant Formation. Bar scale = 250 microns or 0.25 mm.

tion models, the "Dorag" model (Badiozamani, 1973), which requires that a mixing of meteoric and sea water occur, is favored for the origin of the dolomites in the thesis area.

DEPOSITIONAL ENVIRONMENT

The alternation of carbonates and clastics in the lower Quadrant Formation suggests deposition in a marginal marine, neritic to littoral environment. The well-sorted detrital quartz grains are indicative of sands deposited in an agitated environment where the finer-grained particles are selectively winnowed out. Possible depositional environments for the sand grains include bars, barrier islands, and beaches. The bimodality of sand sizes in some quartz arenites may reflect a proximity of the depositional environment to aeolian conditions (Folk, 1968). This interpretation is supported by Saperstone and Ethridge (in press) who consider the Quadrant Formation of southwestern Montana to represent a shallowing-upwards depositional sequence from sandy carbonate tidal flats to an aeolian environment.

The monomineralllic, texturally mature framework grains suggest that the quartz arenite represents a multicycled deposit. The source for the Quadrant sands is believed to have been from a rising land mass located to the west or northwest within the Cordilleran geosyncline. More specifically, a Middle Ordovician (Chazy) sandstone found today in parts of Idaho, northeastern Washington, British Columbia, and Alberta is thought to have been the principal source for the Quadrant sands (Maughan, 1975).

Prior to dolomitization, the dolostones were primarily mudstones and wackestones that were deposited in shallow water carbonate environments. However, these carbonate environments were probably restricted in areal extent due to clastic sediments clouding the water and therefore, inhibiting their growth. The overall epicontinental sea setting hypothesized for the region during latest Mississippian-Pennsylvanian time provided an adequate environment for the mixing of meteoric and sea water to initiate the post-depositional "Dorag" dolomitization processes.

FOSSILS AND AGE

Although fossils are recognized in the lower dolomitic interval of the Quadrant Formation, the samples are too fragmented to permit identification beyond basic phylogenies. Therefore, no age assignment can be presented for the formation in the thesis area.

Outside of the Snowcrest trough, the Quadrant Formation has been assigned a Pennsylvanian (late Atokan to Des Moinesian) age on the basis of fusulinids (Thompson and Scott, 1941) and forams (Henbest, 1956). However, in southwesternmost Montana, the lower beds of the Quadrant Formation are considered to straddle the Mississippian-Pennsylvanian boundary (Wardlaw and Pecora, 1985). Whether or not this age assignment carries through to the lower Quadrant Formation exposed in the thesis area is not known.

STRATIGRAPHIC CORRELATIONS

SOUTHWESTERN MONTANA: THESIS AREA

Within the thesis area three mappable stratigraphic units are recognized. As shown on plate 1, they are, in ascending order: the Conover Ranch Formation, an unnamed limestone unit, and the lower dolomitic interval of the Quadrant Formation. The lower dolomitic interval of the Quadrant Formation is not distinguished as a separate formation (as is the Devils Pocket Formation in central Montana) but rather it is considered to represent a lower carbonate-clastic unit of the predominantly clastic Quadrant Formation. A similar classification scheme for the Quadrant Formation in southwestern Montana has been proposed by Saperstone and Ethridge (in press).

The variations in thickness of the Conover Ranch Formation and the unnamed limestone unit within the thesis area can be attributed to the following factors: one, to differential subsidence along northwest-trending faults within the Snowcrest trough during Late Mississippian-Pennsylvanian deposition (Maughan and Perry, 1982); and two, to post-depositional structural modifications of the units in the Snowcrest Range related to Laramide-age thrusting in southwestern Montana. As previously discussed, the thinner stratigraphic sequence present in the Blacktail Mountains probably represents an interval which was deposited on a tectonically stabler, northwestern flank of the Snowcrest trough. In general, the Conover Ranch Formation in the thesis area thickens to the southwest whereas the unnamed limestone unit attains a maximum thickness at Sunset Peak in the middle of the Snowcrest Range (plate 1). For both units, though, the Snowcrest trough was definitely a depocenter during Late Mississippian-Pennsylvanian time.

During deposition of the Quadrant Formation (Pennsylvanian) within the thesis area, the Snowcrest trough was also a depocenter, but not of the same magnitude as during deposition of the Snowcrest Range Group. However, farther to the southwest, along the Montana-Idaho border, the Snowcrest trough was apparently more deeply developed as the Quadrant Formation thins abruptly from west to east, presumably representing another trough to platform transition zone (Saperstone and Ethridge, in press). Variations in thickness of the lower dolomitic interval of the Quadrant Formation in southwestern Montana are not known.

REGIONAL CORRELATIONS

Difficulty in correlating the Late Mississippian-Early Pennsylvanian units in southwestern Montana to the established stratigraphy in adjacent regions has long been recognized by many workers (McMannis, 1955; Robinson, 1963; Maughan and Roberts, 1967; and Brewster, 1984). Nevertheless, shown on plate 2 are hypothesized correlations of the thesis area lithologic units to the stratigraphic sequences established in central Montana and western Wyoming. At some localities, where measured sections were not formally divided into members or formations, the sections were divided into obvious lithologic units in order to enhance the correlation picture. However, because of this practice, some of the correlations presented herein may be subject to debate.

CENTRAL MONTANA

When comparing the Late Mississippian-Early Pennsylvanian stratigraphic sequence between the thesis area and central Montana, one cannot help but notice that the lithologies of the Conover Ranch Formation, the unnamed limestone unit, and the lower dolomitic interval of the Quadrant Formation are strikingly similar to the lithologies of the Tyler, Alaska Bench, and Devils Pocket Formations of the Amsden Group in central Montana. As shown in stratigraphic cross-section B-B' on plate 2, the lithologic units are apparently continuous between the Big Snowy and Snowcrest troughs, although thinned over the Lombard arch. However, a westward shift of the cross-sectional line from central to southwestern Montana, as shown in stratigraphic cross-section A-A' on plate 2 (see inset index map), indicates that the limestone unit is nearly nonexistent in southwestern Montana and that the correlative Late Mississippian-Early Pennsylvanian stratigraphic sequence is much thinner. This, however, is not the case for all of the Late Mississippian-Early Pennsylvanian stratigraphic sequences in southwestern Montana as was shown in stratigraphic cross-section B-B' on plate 2. Thus, it appears that the placement of the line of stratigraphic cross-section in southwestern Montana is crucial in deciphering the relative thickness and lithologic sequence of the Late Mississippian-Early Pennsylvanian strata in the region. For example, a cross-sectional line using stratigraphic data from measured section localities within the Snowcrest Range (i.e., B-B'), supports Maughan and Roberts (1967) three-fold lithologic classification of the "Amsden" in Montana. However, a cross-sectional line <u>not</u> utilizing the data from the Snowcrest Range (i.e., A-A') will suggest that a slightly different lithologic sequence exists in southwestern Montana. This latter type of cross-sectional line (A-A') represents the Conover Ranch-Quadrant sequence documented by Wardlaw and Pecora (1985). Although, Wardlaw and Pecora (1985) acknowledge that the Conover Ranch Formation contains "...lesser units of thin-bedded marine limestone", they fail to recognize the regional stratigraphic significance of the limestone lithology between the Conover Ranch and Quadrant Formations in southwestern Montana. However, in this study, the limestone unit is recognized as a thick (325 feet average), mappable stratigraphic unit throughout the Snowcrest Range and vicinity and therefore, deserves to be formally recognized in the Late Mississippian stratigraphic nomenclature of southwestern Montana. As previously suggested, in order to keep with the new nomenclature, perhaps the limestone unit should be considered as a member of the Conover Ranch Formation. In addition, by incorporating the limestone unit into the nomenclature, the name "Snowcrest Range" used in the title of the new group would be more accurately represented.

WYOMING

Correlating the Late Mississippian-Early Pennsylvanian lithologic sequences within the thesis area to the Amsden Formation of Wyoming proves to be very challenging. The presence of the Beartooth platform between the Snowcrest trough and the Wyoming basin during latest Mississippian time apparently separated the two regions into distinct depositional basins. Despite this separation, the Late Mississippian rocks between southwestern Montana and western Wyoming are characterized by common brachiopod assemblages which indicate that the two regions were periodically connected by a seaway to permit a mixing of fauna and depositional assemblages. As a consequence, the lithologic sequences exposed today between southwestern Montana and western Wyoming (e.g., the Beartooth platform) represent a mixture of the two Late Mississippian ("Amsden") depositional sequences.

Despite this problem, two lines of stratigraphic section presented on plate 2 (C-C' and D-D') depict interpretive stratigraphic relationships of the Late Mississippian-Early Pennsylvanian units between the Snowcrest trough and the Wyoming basin. The stratigraphic correlations presented are based partly on lithology and partly on brachiopod biostratigraphy. According to J. Thomas Dutro, Jr. (personal communication, 1985), the brachiopods collected within the unnamed limestone unit in the thesis area are equivalent to brachiopod species of Foraminiferal Zone 19 and highest Foraminiferal Zone 18 of the Amsden Formation in western Wyoming (Anthracospirifer welleri-shawi brachiopod zone) (figure 45). Therefore, based on this assignment, the unnamed limestone unit in the thesis area is assigned a Late Mississippian (latest Chesterian) age and is considered to be stratigraphically correlative to the lower part of the Ranchester Limestone Member of the Amsden Formation in western Wyoming. Accordingly, based solely on lithologies, the Conover Ranch Formation is correlative to the upper part of the Horseshoe Shale Member of the Amsden Formation while the lower dolomitic interval of the Quadrant Formation is correlative to the upper part of the Ranchester Limestone. A similar stratigraphic correlation of the Late Mississippian-Early Pennsylvanian rocks between southwestern Montana and western Wyoming has been devised by Sando and others (1975, plate 10, C-C').

Correlating the brachiopod collection of the thesis area to documented collections from the Alaska Bench Formation of the Amsden Group in central Montana by either Easton (1962) or Maughan and Roberts (1967) is not so successful. Of the brachiopod species, only Orbiculoidea wyomingensis is correlative between the Alaska Bench Formation and the unnamed limestone unit. However, it is speculated that other similar species or affinities of brachiopods exist between the two regions, particularly in either the Orthotetes or Anthracospirifer genera, but as of this time, these biostratigraphic relationships have not been recognized.

Combining lithostratigraphic and biostratigraphic correlations, one can conclude that the unnamed limestone unit in the thesis area is correlative to both the Alaska Bench Formation of

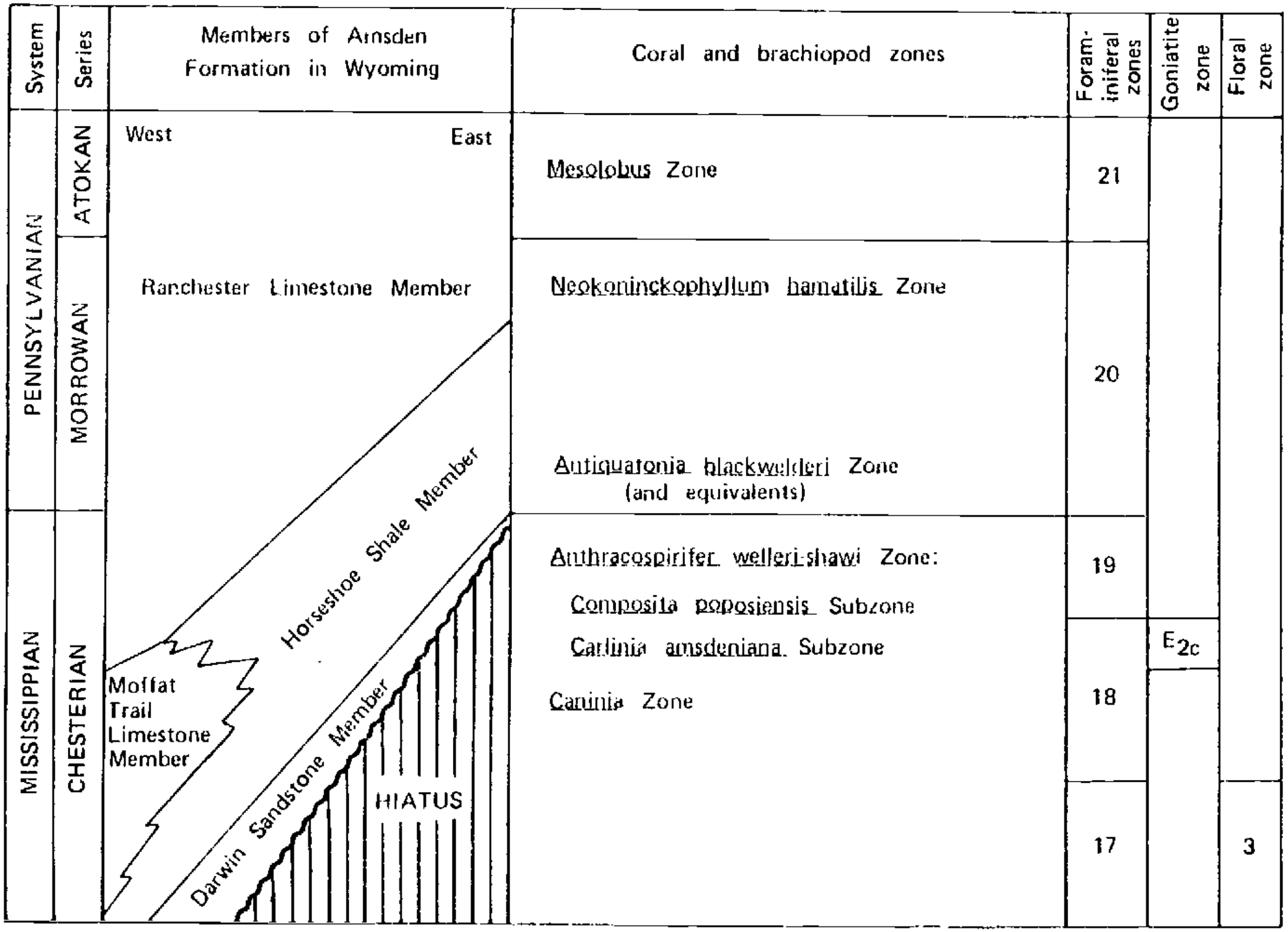


Figure 45. Distribution of faunal and flora zones in the Amsden Formation of Wyoming. From Sando and others, 1975.

the Amsden Group in central Montana and the Ranchester Limestone Member of the Amsden Formation in western Wyoming. For this reason, the limestone unit in the thesis area was left unnamed to avoid complicating the nomenclature of the newly proposed Snowcrest Range Group. Stemming from the stratigraphic relationships between the Alaska Bench, unnamed limestone, and lower Ranchester Limestone from central Montana to western Wyoming via the Snowcrest Range, it follows that the Tyler, Conover Ranch, and upper Horseshoe Shale and the Devils Pocket, lower dolomitic interval of the Quadrant Formation, and the upper Ranchester Limestone also share this same stratigraphic relationship. Interestingly enough, lithostratigraphic criteria correlate the "Amsden" from southwestern to central Montana while biostratigraphic criteria correlate the "Amsden" from southwestern Montana to western Wyoming. However, as previously stated, it is believed that further paleontologic studies of the "Amsden" in Montana will probably reveal that Late Mississippian-Early Pennsylvanian biostratigraphic correlations exist between the Snowcrest and Big Snowy troughs as well.

CONCLUSIONS

In addition to illustrating the stratigraphic relationships of the lithologic units in the thesis area to the "Amsden" of central Montana and western Wyoming, the stratigraphic sections also suggest several other characteristics of the Snowcrest trough. The first is the influence of the trough on Late Mississippian-Early Pennsylvanian sedimentation patterns along the western margin of the northern Cordilleran platform. As shown on an isopach map (figure 46) incorporating the strata between the Lombard Limestone and the Quadrant Formation, the Snowcrest trough was definitely a depocenter during this time period. The second characteristic, also depicted on figure 46, is the relatively narrow northeast-southwest-trending nature of the Snowcrest trough across the platform until opening up into the deeper waters of the miogeosyncline to the west. A similar restricted configuration for the trough during Big Snowy (Lombard) deposition has been postulated by Blake (1959).

Also of interest is the affinity of the brachiopods collected within the unnamed limestone unit in the Snowcrest Range to those in the lower Ranchester Limestone Member of the Amsden Formation in western Wyoming. This affinity indicates that an open seaway existed between the two regions during latest Chester time to permit a comingling of the fauna. Similar Late Mississippian faunal affinities between southwestern Montana and western Wyoming for the underlying Big Snowy rocks (Lombard Limestone) have been noted in the Blacktail Mountains by Pecora (1981) and in the Snowcrest Range by Byrne (personal communication, 1985). It is speculated that an open seaway periodically existed either across the Beartooth platform or along the westernmost margin of the northern Cordilleran platform before opening up into the miogeosyncline to the west during latest Mississippian time.

Of the two regional stratigraphic correlations, one would have to favor, based on Late Mississippian-Early Pennsylvanian

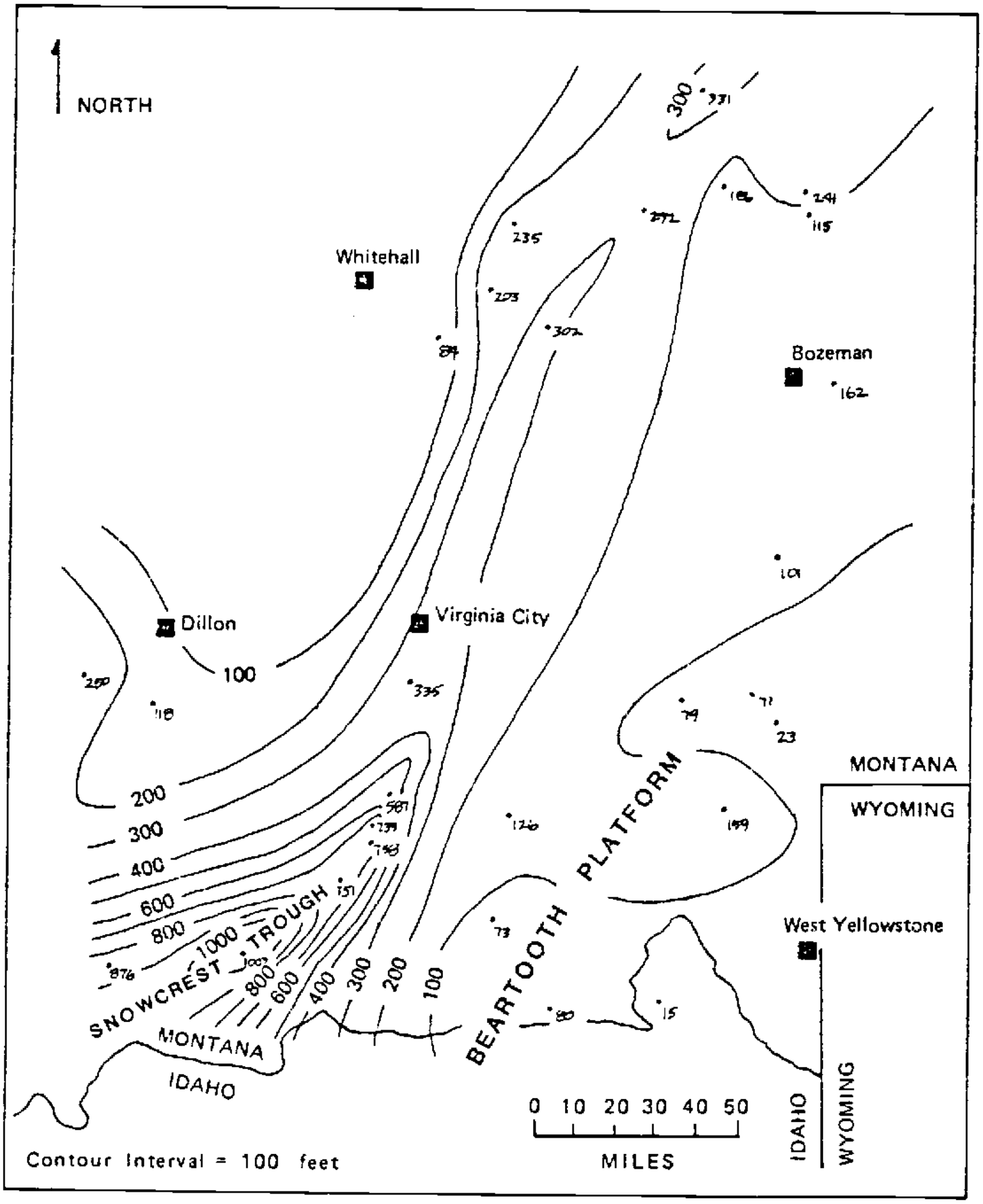


Figure 46. Isopach map of strata between the Big Snowy Group (Lombard Limestone) and Quadrant Formation, figure not palinspatically restored. Thickness information derived from the follwing sources: Brewster, 1984; Gardner and others, 1946; Goodhue, personal comm.; Hadley, 1980; Harris, 1972; Honkola, 1949; Mann, 1954; Moran, 1971; Witkind, 1969; Witkind, personal comm., 1985; and this thesis.

structural settings and the nature of lithologic assemblages, that the stratigraphic units in the thesis area have more in common with the Amsden Group of central Montana than with the Amsden Formation of western Wyoming. Although the "Amsden" thins over the Lombard arch, the lithologic units appear to have been continuous during Late Mississippian time between the Snowcrest and Big Snowy troughs along a relatively narrow, north-south-trending strip.

CARBONIFEROUS GEOLOGIC HISTORY

During the Carboniferous, a combination of epeirogenic movements and eustatic sea level changes caused the northern Cordilleran platform to be inundated and drained several times. During early Kinderhookian-early Meramecian time, transgression of a shallow sea onto the northern Cordilleran platform resulted in the deposition of the Madison Group carbonate sequences. The widespread occurrence of the Madison Group carbonates throughout most of Montana and Wyoming indicates that the platform subsided relatively uniformly as a single entity during this time interval. At the beginning of latest early Meramecian time, epeirogenic uplift and eustatic sea level drop caused the sea to withdraw from the platform and be confined to the miogeosynclinal region (Gutschick et al., 1980). As a result of subaerial exposure on the uplifted northern Cordilleran platform, a karst topography developed on the upper limestones of the Madison Group (Mission Canyon Formation).

The next major transgression of the sea onto the northern Cordilleran platform began during latest Meramecian time. In this transgression, however, localized differential subsidence along the western margin of the platform restricted the transgression of the sea to two arms: one in southwestern Montana and the other in western Wyoming. In southwestern Montana, the initial sediments deposited were the Kibbey sands of the Big Snowy or Snowcrest Range Groups, whereas in western Wyoming, the initial deposits were the Darwin sands of the Amsden Formation. As the sea continued to transgress eastward onto the northern Cordilleran platform during earliest Chesterian time, "...the embryonic Wyoming and Big Snowy-Williston basins were clearly evident as depositional entities, separated by a large peninsular area, the incipient Southern Montana arch" (Sando, 1976). In addition to being separated, the two regions also were characterized by distinct structural stabilities during the latest Mississippian-Pennsylvanian time. The Wyoming shelf (basin) was relatively stable whereas the Big Snowy and Snowcrest troughs in Montana were tectonically unstable basins. Bordering the Big Snowy trough to the north was the Alberta shelf, another relatively stable part of the northern Cordilleran region. Thus, the latest Mississippian tectonic setting of the northern Cordilleran platform can be generalized as consisting of two relatively stable parts, the Wyoming and Alberta shelves, separated by two tectonically related, unstable depositional basins, the Snowcrest and Big Snowy troughs (figure 47).

During latest Chesterian time, epeirogenic uplift in central Montana (Big Snowy uplift) ended Big Snowy Group deposition as the sea was drained to the west out of the Big Snowy trough towards the miogeosyncline. In the Snowcrest trough though, the late Chesterian sea appears to have remained as a shallow arm of the sea on the western margin of the northern Cordilleran platform. At the time of maximum sea regression caused by the Big Snowy uplift, the first clastic sediments of the Conover Ranch Formation in the thesis area were being deposited in the Snowcrest trough. At the same time in central Montana, nearshore deltaic and fluvio-

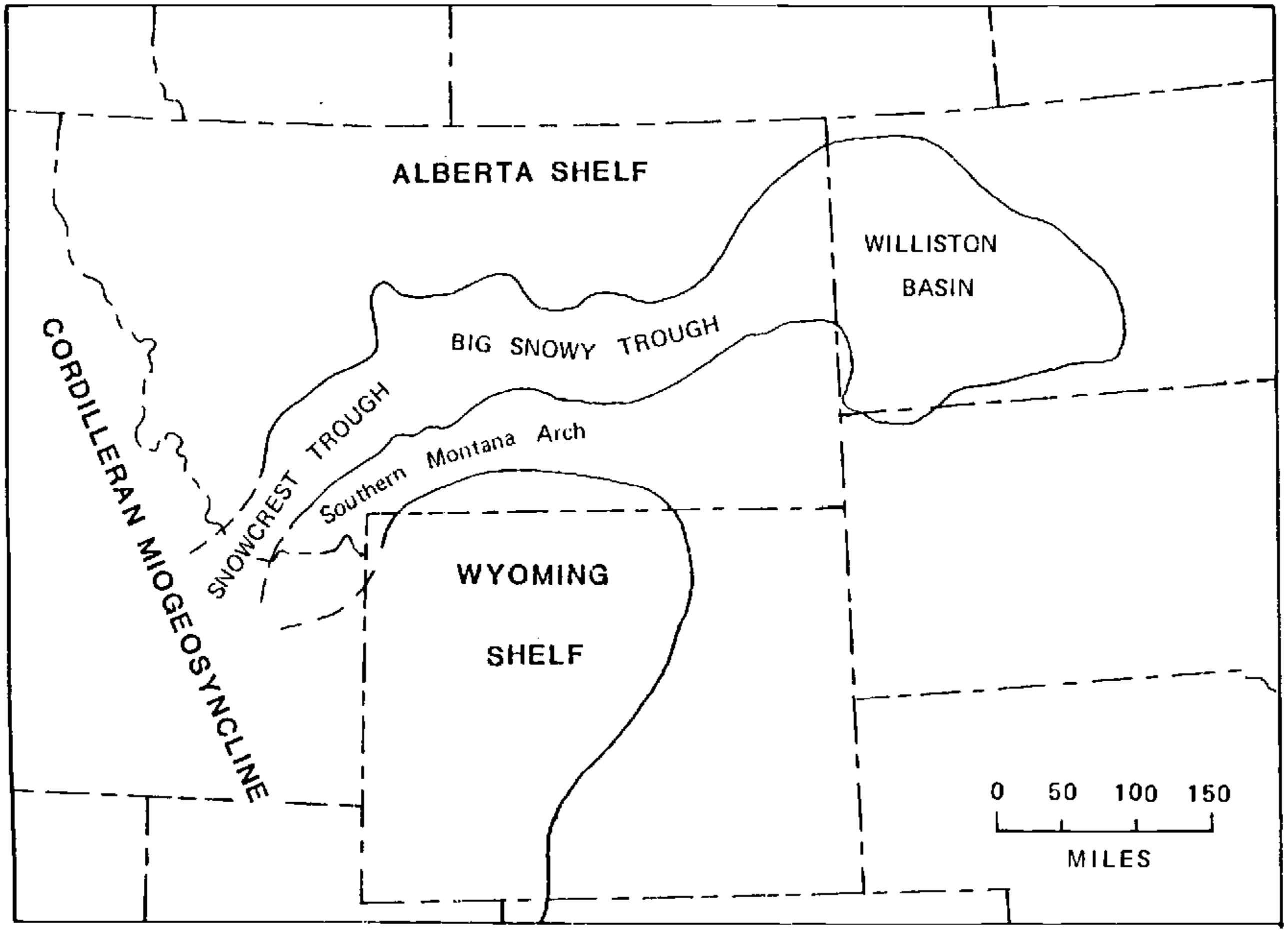


Figure 47. Paleotectonic setting of Montana during the latest Mississippian time.

lacustrine sands and silts of the Stonehouse Canyon Member of the Amsden Group were being deposited on top of the Heath Formation of the Big Snowy Group (Maughan, 1984). Renewed late Chesterian subsidence within central Montana once again permitted an eastward transgression of the sea into the Big Snowy trough.

In contrast to the tectonic activity in Montana during latest Chesterian time, the Wyoming basin was relatively stable. As a consequence, the sea continued to transgress slowly and enlarge in areal extent in the Wyoming basin. It is speculated by Sando and others (1975) that the continual enlargement of the sea within the Wyoming basin eventually led to the breaching of the Southern Montana arch during latest Chesterian time and thereby allowed a comingling of the "Amsden" depositional sequences on the northern Cordilleran platform.

As the sea slowly transgressed into central Montana, the waters within the Snowcrest trough gradually became clearer as a result of the fine-grained sediments, characteristic of the Conover Ranch Formation, being deposited farther to the east in a complex deltaic setting within the Big Snowy-Williston basins (Maughan, 1984). As a consequence of cleaner waters within the Snowcrest trough, a normal marine carbonate environment developed and is represented in the strata of southwestern Montana today by the unnamed limestone unit documented in this study. As the sea continued to transgress, the same environmental changes occurred within central Montana, causing the clastic sedimentation of the Tyler Formation to give way to the predominantly carbonate sedimentation of the Alaska Bench Limestone. This limestone sequence is considered to represent the latest Chesterian-earliest Morrowan sedimentation in central Montana (Davis, 1983). At the end of Morrowan time, the sea and the limestone sequence within the Big Snowy trough reached maximum areal extent.

During latest Morrowan or earliest Atokan time, a rising land source developed in north-central Idaho from which clastic sediments were shed to the east into the Snowcrest trough and onto the western margin of the northern Cordilleran platform. The initial clastic sediments deposited from this uplift are represented by the lower dolomitic sandstones of the Quadrant Formation in the thesis area. At approximately the same time in central Montana, a slow westward regression of the sea began out of the Big Snowy trough. This regressive phase persisted on the northern Cordilleran platform until Late Pennsylvanian (Missourian-Virgilian) time. As the sea slowly retreated, it is speculated that the environmental conditions became favorable for post-depositional dolomitization processes to occur within the underlying Late Mississippian-Early Pennsylvanian strata. Today, these dolomitized units are represented by the lower dolomitic interval of the Quadrant Formation and the Devils Pocket Formation of the Amsden Group in southwestern and central Montana, respectively.

In summary, the Late Mississippian-Early Pennsylvanian units in the thesis area reflect a single major transgressive-regressive depositional sequence in the northern Cordilleran region of Montana. The fluctuating sea level across this region is believed to have been primarily caused by epeirogenic subsidence and uplift within the tectonically unstable Big Snowy trough and not to eustatic sea level fluctuations during this time period. However, recent studies by Saunders and others (1979) and Ross and Ross (1985) suggest that numerous eustatically controlled transgressive-regressive depositional sequences dominated the late Paleozoic on a worldwide scale. For example, during the mid-Carboniferous (Chesterian-Morrowan) time interval in the Ozark shelf region, Saunders and others (1979) have hypothesized eleven eustatic transgressive-regressive depositional cycles. However, in the northern Cordilleran region during the Late Mississippian-Early Pennsylvanian, neither biostratigraphic nor lithostratigraphic evidence was found to support such sea level fluctuations. Of course, one might speculate that the Late Mississippian-Early Pennsylvanian seas transgressed and regressed across the northern Cordilleran platform in a series of pulses but the extent to which these pulses might correlate to the "worldwide" eustatic transgressive-regressive events documented by Saunders and others (1979) and Ross and Ross (1985) is not known.

HYDROCARBON SOURCE ROCK ANALYSIS

Although an economically successful oil or gas field has yet to be discovered in southwestern Montana, Perry and others (1983) suggest that the

> "petroleum potential of the southern part of the southwest Montana thrust belt is enhanced by the intersection of two mutually interferring structural trends: the northeast trending Blacktail-Snowcrest uplift with inferred uplift-flank thrusting, and the trend of younger Sevier-type Tendoy and Medicine Lodge thrusts and associated folds."

In light of this situation, organic-rich carbonate rocks within the unnamed limestone unit in the Snowcrest Range were collected and analyzed for hydrocarbon source rock potential. Although the "Amsden" is generally not considered as a primary source rock for hydrocarbons in the northern Rocky Mountain region, the proximal relationship of these organic-rich rocks in the Snowcrest Range to potentially correlative lithologies beneath the Overthrust Belt deemed it worthwhile to investigate the source rock potential.

In previous source rock analyses of "Amsden" lithologies in the Williston basin and Big Snowy trough, the results of the studies have been mixed. In the Williston basin, organic-rich shales within the Tyler Formation of the Amsden Group have been reported as the principal source rock for oil deposits within the Tyler sandstones (Williams, 1974). However, in central Montana, the Heath Formation of the Big Snowy Group, rather than the Tyler Formation of the Amsden Group, was found to be the principal source rock for oil accumulations within the Tyler sandstones (Swetland et al., 1978). Additionally, in central Montana, the oil shale potential of the Heath Formation has been documented to be much more favorable than the Tyler Formations (Cox and Cole, 1981). In the thesis area, the Lombard shales (Heath correlatives) also appear to be better hydrocarbon source rocks than the Conover Ranch shales (Tyler correlatives) (personal communication, Byrne, 1985). However, organic-rich carbonate intervals within the unnamed limestone unit in the Snowcrest Range were recognized and, subsequently, collected for hydrocarbon source rock analysis.

The hydrocarbon source rock analyses were performed by Tenneco Oil Company and consisted of the following analyses: Vitrinite Reflectance, Spore Color Alteration Index, Total Organic Carbon Content, Extractable Hydrocarbons, Kerogen Analysis (type and percentage), and Rock-Eval pyrolysis. The results of these analyses are shown in tables 1 and 2.

According to hydrocarbon source rock standards used by Tenneco Oil Company (see Table 3), the samples analyzed from the unnamed limestone unit are generally poor hydrocarbon source rocks. Although one half of the samples had "fair" total organic carbon contents (based on the carbonate standard), a thermal maturity within the oil and gas generating window, and a favorable type of kerogen material (sapropelic) for hydrocarbon generation, the overall "poor" levels of kerogen content and the complete absence of extractable hydrocarbons (see Table 1) renders the samples questionable as hydrocarbon source rocks. Of course, the low levels of kerogen and complete absence of soluble hydrocarbons can be attributed to surface weathering processes whereby the C15+ hydrocarbons have been degredated.

TABLE 1

Results of hydrocarbon source rock analyses.

					"KEROGEN TYPES"						
	SPORE	VITRINITE	TOTAL ORGANIC	EXTRACTABLE	INERTINITE	HUMIC		EXINITE		SAPROPELIC	
SAMPLE	COLOR	REFLECTANCE	CARBON CONTENT (%)	HYDROCARBONS (ppm)	%	%	ppm	%	ppm	%	ppm
GC-1	3	0.81	0.17	0.0	-	-	-	-	-	-	-
GC-2	3	0.76	0.24	0.0	4	8	192	4	96	84	2016
GC-3	4	1.12	0.44	0.0	26	14	616	2	88	58	2552
GC-4	3	0.45	0.23	0.0	22	36	828	22	506	20	460
GC-5	3	0.93	0.11	0.0	-	-	-	-	-	-	-
GC-6	4	0.48	0.21	0.0	42	10	210	2	42	46	966
GC-7	3	0.72	0.13	0.0	24	18	234	16	208	42	546
GC-8	3	0.84	0.16	0.0	-	-	-	-	-	-	-
GC-9	3	0.51	1.07	0.0	-	-	-	-	-	-	-
GC-10	3	0.78	0.43	0.0	12	2	86	0	0	86	3784

TABLE 2

Results of Rock-Eval pyrolysis.

SAMPLE	TMAX C	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	PI	HI	OI
GC-3	428	0.05	0.70	0.30	0.07	159	68
GC-9	431	0.08	2.44	0.36	0.03	228	33
GC-10	428	0.03	0.60	0.41	0.05	139	95

TMAX = Temperature Index, degrees C.
S1 = Free hydrocarbons, mg HC/g of rock
S2 = Residual hydrocarbon potential, mg HC/g of rock
S3 = CO_2 produced from kerogen pyrolysis, mg CO_2/g of rock
PI = S1/(S1 + S2)
HI = Hydrogen Index, mg HC/g organic carbon
OI = Oxygen Index, mg CO_2/g organic carbon

TABLE 3

Analysis of unnnamed limestone unit samples according to Tenneco Oil Company's standards for hydrocarbon source rock evaluation (Ruffin, 1980). A) Vitrinite Reflectance, B) Spore Color Alteration, C) Total Organic Carbon Content, and D) Kerogen Types and Content.

A) MATURATION LEVEL: Vitrinite Reflectance

	Number of samples	Probable Hydrocarbon
Immature (<0.55)	3	Gas
Transitional (0.55–0.65)	1	Gas & Minor Oil
Mature (0.65–1.0)	5	Gas & Oil
Very Mature (1.0–1.5)	1	Wet Gas
Advanced (>1.5)	0	Gas

B) MATURATION LEVEL: Spore Color Alteration Index

	Number of samples	Probable Hydrocarbon
Immature (1)	0	Gas
Transitional (2)	0	Gas & Minor Oil
Mature (3)	8	Gas & Oil
Very Mature (4)	2	Wet Gas
Advanced (5)	0	Gas

C) TOTAL ORGANIC CARBON CONTENT (% of rock) *

	Number of samples
Poor (<0.2)	4
Fair (0.2–0.5)	5
Rich (0.5–1.0)	1
Very Rich (>1.0)	0

* based on the carbonate standard

D) KEROGEN TYPES AND CONTENT (ppm of rock)

	HUMIC	EXINITE	SAPROPELIC
Poor (<2000)	6	6	3
Fair (2000–5000)	0	0	3
Rich (5000–10,000)	0	0	0
Very Rich (>10,000)	0	0	0

Because of low kerogen levels, Rock-Eval pyrolysis was limited to only three samples. As a consequence, the data form this analysis is limited and, therefore, neither a thermal maturation path nor a kerogen type, as defined by Tissot and Welte (1978), can be distinguished on a Van Krevelan diagram (figure 48). However, the S1 and S2 peaks of sample GC-9 generated during the analysis suggest that this particular sample has potential to be a marginal hydrocarbon source rock as hydrocarbons were generated upon heating of the sample (Espitalie et al., 1977). Nevertheless, despite this somewhat favorable indication, the overall hydrocarbon source rock potential of the unnamed limestone unit in southwestern Montana would still have to be regarded as "poor".

As previously mentioned, the hydrocarbon source rock potential of the Lombard Limestone in southwestern Montana appears to be promising (Swetland, et al., 1978, Byrne, personal communication, 1985). With this in mind, a potential reservoir rock in southwestern Montana would be the Quadrant Formation. In Wyoming, the Quadrant-Tensleep Formation is a proven reservoir rock accounting for over 26% of that states oil and gas production (Wyoming Oil and Gas Conservation Committee, 1981). In south-central Montana, the Quadrant-Tensleep Formation produces oil in the northern Big Horn basin region (figure 49). In southwestern Montana, the Quadrant Formation appears to be a likely reservoir rock. However, in order to accurately assess the reservoir potential of the Quadrant sandstones in the region, future porosity and permeability studies are required.

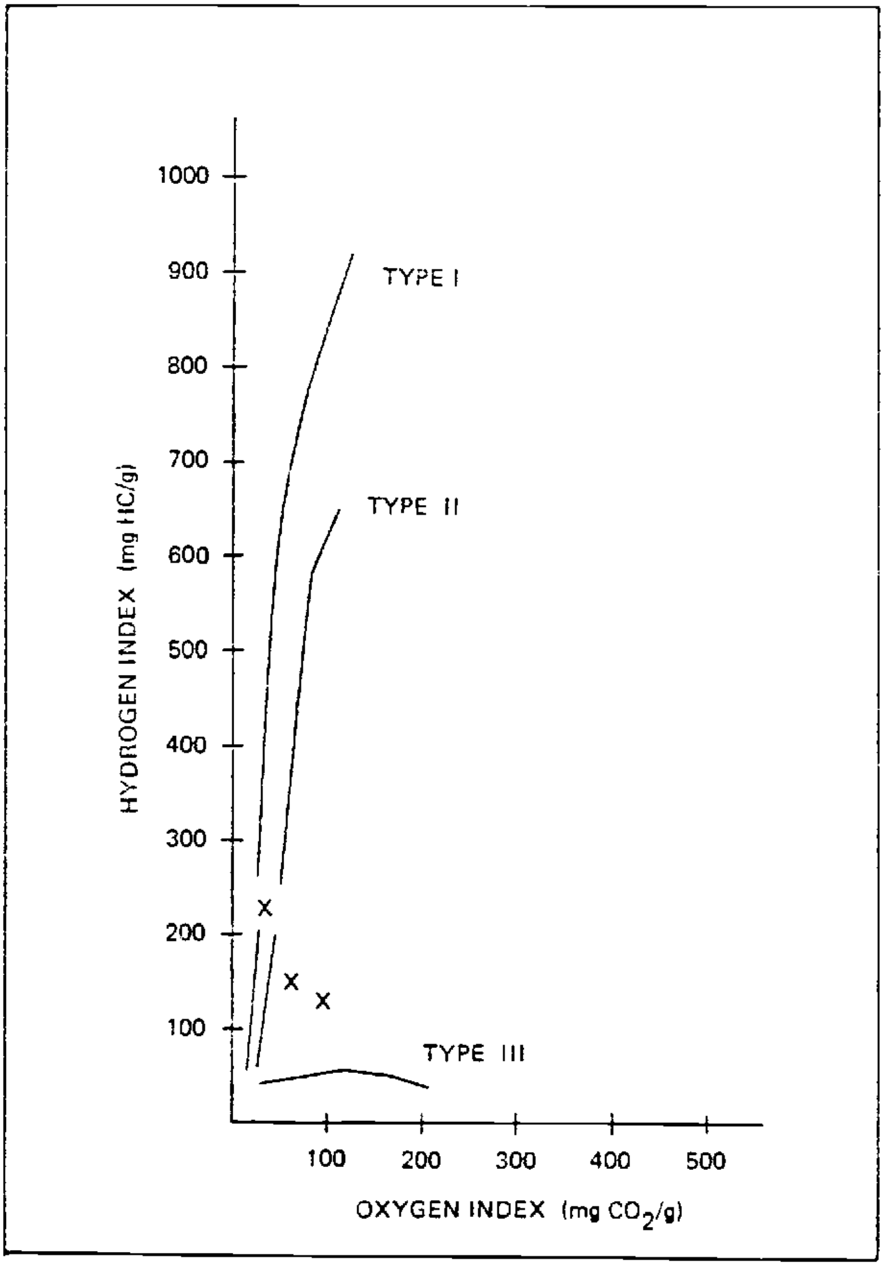


Figure 48. Van Krevelan plot. Hydrogen Index versus Oxygen Index for whole-rock Rock-Eval pyrolysis samples.

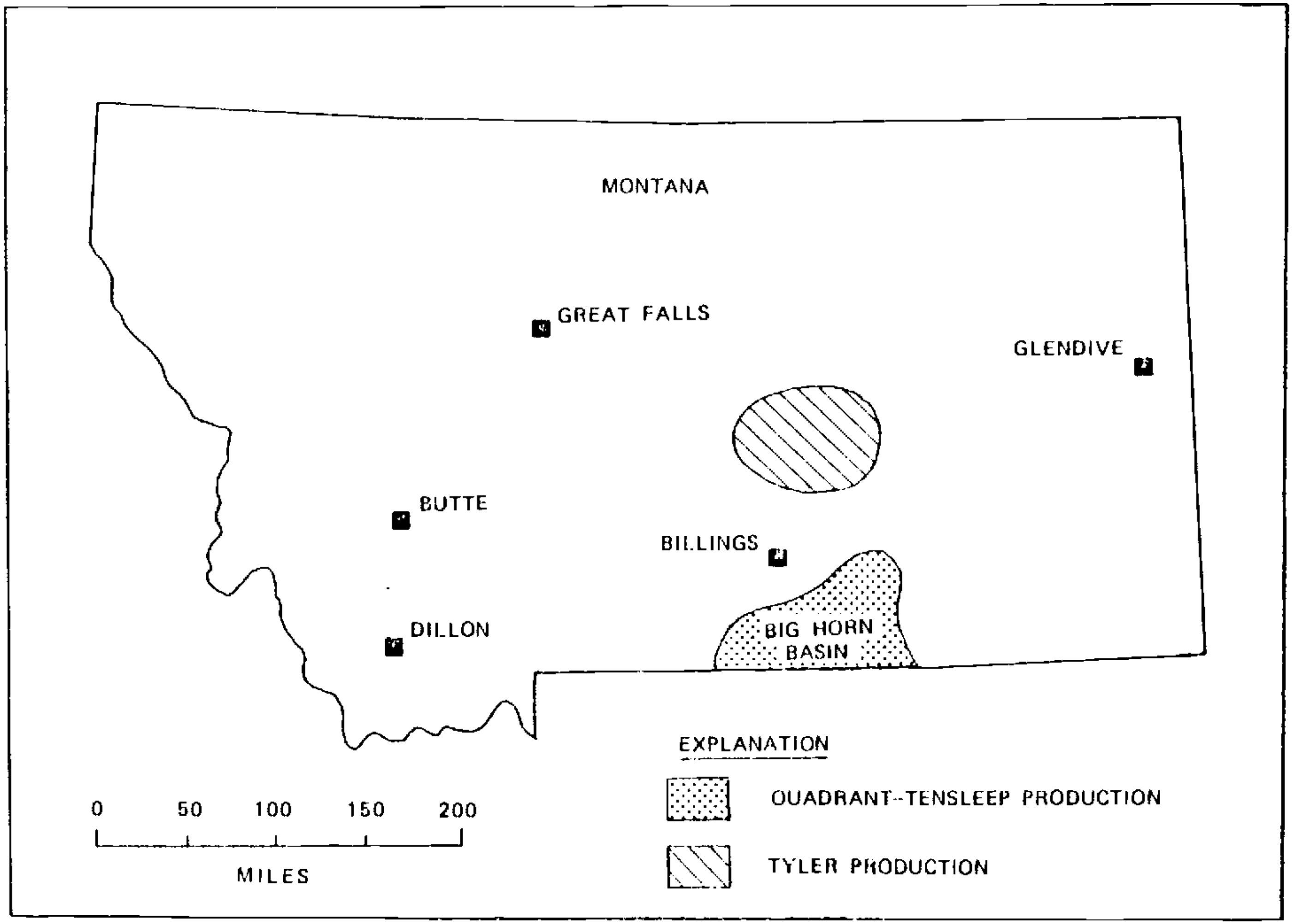


Figure 49. Location map of Quadrant-Tensleep and Tyler oil fields in Montana.

Although the Tyler Formation sandstones are oil and gas targets in central Montana (figure 49), in southwestern Montana, the channel sandstones within the Conover Ranch Formation (Tyler correlatives) are considered too sporadic and small in occurrence to be viable economic reservoir rocks.

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APPENDIX

SHEEP CREEK

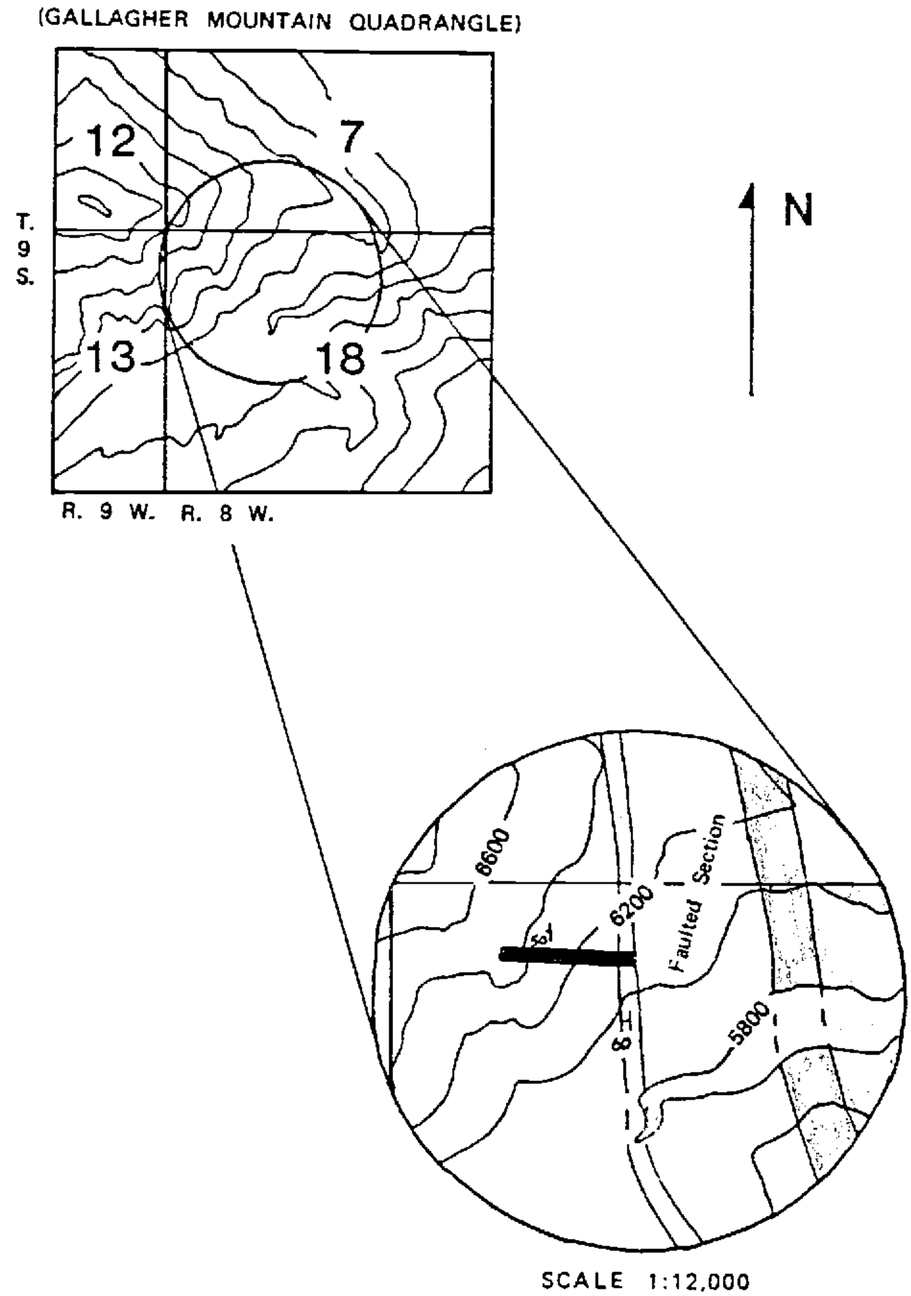

Figure 50. Bedrock geology and location of measured section transverse at Sheep Creek locality, Blacktail Mountains, Beaverhead County, Montana. See page 137 for explanation.

LEGEND FOR FIGURES 50-59

STRATIGRAPHIC KEY

Quaternary	Covered	
Triassic	Undifferentiated Triassic	
Permian	Phosphoria Formation	
Pennsylvanian	Quadrant Formation	
?	Unnamed Limestone Unit	
Mississippian	Conover Ranch Formation	Snowcrest Range Group
	Lombard Limestone	
	Kibbey Sandstone	
	Mission Canyon Limestone	
	Undifferentiated Mississippian	

Measured Section Transverse

Thrust Fault

50° Strike and Dip of Bedding

47° Strike and Dip of Overturned Bedding

SHEEP CREEK

Terminal Point: NW 1/4 NW 1/4 NW 1/4, sec. 18, T. 9 S., R. 8 W., Gallagher Mountain 7.5 minute quadrangle, Beaverhead County, Montana. At base of large Quadrant cliff on the northwest side of Sheep Creek Canyon, about 600' above canyon floor; elevation about 6400 feet.

Thickness
in feet

QUADRANT FORMATION (incomplete)

37) Quartz arenite, calcite-cemented, cliff-former, very pale orange (10YR 8/2), fine-grained, well-indurated, thickly bedded with localized 1-2' trough cross-bed sets with individual laminae containing heavy mineral layers........................170

36) Quartz arenites, calcite-cemented, series of 2-5' ledge-formers, white (N 9), locally hematite stained, fine-grained, medium-bedded with isolated planar cross-bed sets..................................44

35) Covered interval..................................5

34) Quartz arenites, calcite-cemented, series of 2-4' ledge-formers, white (N 9), locally hematite stained, fine-grained, porous, medium-bedded to massive.................62

33) Covered interval.................................15

32) Quartz arenites, calcite-cemented, series of 3-6' ledge-formers, white (N 9), locally hematite cemented, fine-grained, porous, massive.................................57

31) Quartz arenite, calcite-cemented, subdued ledge-former, pale yellowish orange (10YR 8/6), thin- to thick-bedded......................17

30) Siltstone, calcareous, subdued ledge-former, very pale orange (10YR 8/2), massive..2

29) Quartz arenite, calcite-cemented, subdued ledge-former, very light gray (N 8), fine-grained, porous, medium-bedded...................12

28) Quartz arenite, calcite-cemented, ledge-former, pale yellowish orange (10YR 8/6), fine-grained, thin- to medium-bedded.............5

27) Covered interval..................................9

26) Quartz arenite, silica-cemented, ledge-former, white (N 9), fine-grained, porous, medium-bedded..................................12

25) Quartz arenite, calcite-cemented, ledge-former, very pale orange (10YR 8/2), fine-grained, medium-bedded......................3

24) Quartz arenite, silica-cemented, ledge-former, white (N 9), locally hematite stained, fine-grained, medium-bedded............12

TOTAL MEASURED PART OF QUADRANT FORMATION...........<u>425</u>

Contact. - Quadrant/Conover Ranch: sharp, slightly undulating, locally scour-and-fill structures.

CONOVER RANCH FORMATION

23) Recrystallized limestone, ledge-former, medium light gray (N 6), massive, brecciated with numerous calcite veins................4

22) Quartz arenite, calcite-cemented, ledge-former, very pale orange (10YR 8/2), fine-grained.......................................1

21) Wackestone, ledge-former, light olive gray (5Y 6/1), thinly bedded with brachiopod and crinoid fragments concentrated in thin layers...3

20) Quartz arenite, calcite-cemented, ledge-former, very pale orange (10YR 8/2), thinly bedded with a basal contact containing limestone rip up clasts from subjacent unit..................................1

19) Wackestone, ledge-former, light olive gray (5Y 6/1), brachiopod and crinoid fragments, local vuggy porosity, fractured...........1

18) Quartz arenite, calcite-cemented, ledge-former, light brown (10YR 7/4), fine-grained, scour-and-fill structures developed along basal contact....................1

17) Wackestone, ledge-former, light olive gray (5Y 6/1), medium-bedded with brachiopod and crinoid fragments, local vuggy porosity, 3" chert stringers....................3

16) Siltstone, calcareous, poorly exposed, grayish pink (5R 8/2)............................15

15) Wackestone, subdued ledge-former, light gray (N 7), massive, brachiopod and crinoid fragments...............................1

14) Quartz arenite, calcite-cemented, ledge-former, light brown (5YR 6/4), fine-grained......................................3

13) Siltstone, both dolomite- and calcite-cemented, poorly exposed, yellowish gray (5Y 8/1) on fresh surfaces, thinly bedded, locally bioturbated.....................28

12) Limestone conglomerate, well-rounded pebble-sized clasts, ledge-former, color ranging from light olive gray (5Y 6/1) to pale red (10R 6/2)................................2

11) Siltstone, calcareous, poorly exposed, color ranging from yellowish gray (5Y 7/2) to pale red (10R 5/2)......................13

10) Limestone conglomerate, well rounded pebble-sized clasts, ledge-former, color ranging from light olive gray (5Y 6/1) to pale red (10R 6/2), crudely cross-bedded..........1

9) Shale/siltstone, calcareous, poorly exposed, trenching reveals pale reddish brown (10R 4/4) to medium light gray (N 6) color..6

8) Grainstone, subdued ledge-former, light brownish gray (5YR 6/1)..........................3

7) Siltstone, calcareous, poorly exposed, fresh color: light gray (N 7).....................4

6) Grainstone, ledge-former, medium light gray (N 7), medium-bedded, flaggy habit, subtle rippled surfaces, localized 2 x 6" limestone pebble conglomerate and sandstone lenses................................8

5) Limestone conglomerate, pebble- to cobble-sized clasts, ledge-former, color ranging from light olive gray (5Y 6/1) to pale red (5R 6/2), limestone clasts are well-rounded and contain poorly preserved brachiopod and crinoid fragments, the unit is crudely cross-bedded..........................3

4) Siltstones, calcareous, poorly exposed............6

3) Limestone conglomerate, pebble- to cobble-sized clasts, ledge-former, color ranging from light olive gray (5Y 6/1) to pale red (5R 6/2), limestone clasts are well-rounded and contain poorly preserved brachiopod and crinoid fragments, the unit is crudely cross-bedded..........................2

2) Quartz arenite, calcite-cemented, subdued ledge-former, yellowish gray (5Y 6/1), thinly bedded with localized planar cross-bed sets, interbedded with grainstone lenses (3 x 6")..................................5

1) Limestone conglomerate, pebble- to cobble-sized clasts, ledge-former, color ranging from light olive gray (5Y 6/1) to pale red (5R 6/2), limestone clasts are well-rounded, slightly imbricated, and contain poorly preserved brachiopod and crinoid fragments. The unit is crudely cross-bedded with some sets containing a basal pebble layer, the lower contact appears undulatory..4

TOTAL CONOVER RANCH FORMATION.....................118

Contact. - Conover Ranch/Lombard Limestone: sharp, undulating, probably erosional.

Initial Point: NE 1/4 NW 1/4 NW 1/4, sec. 18, T. 9 S., R. 8 W., Gallagher Mountain 7.5 minute quadrangle, Beaverhead County, Montana. On northwest side of Sheep Creek Canyon, about 350' above canyon floor; elevation about 6050 feet.

RUBY GAP

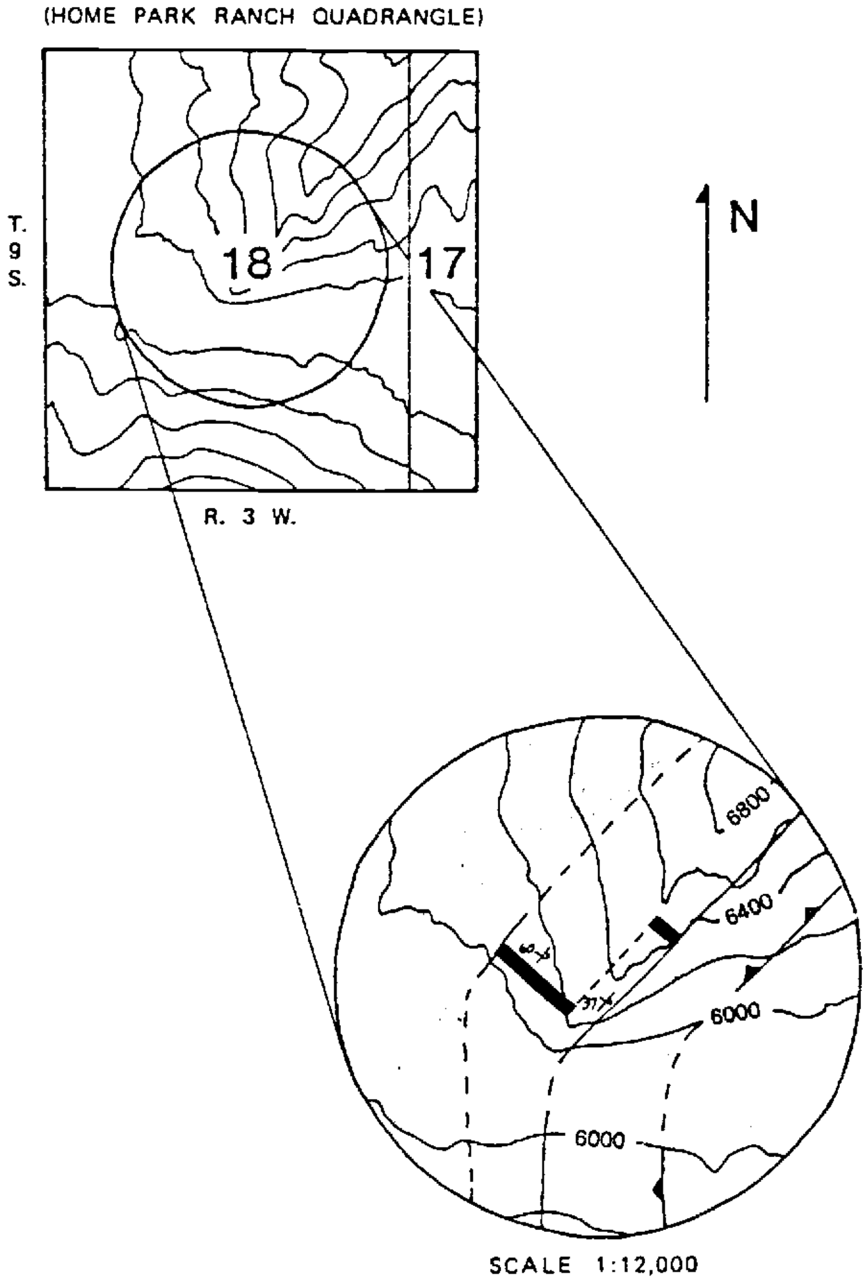

Figure 51. Bedrock geology and location of measured section transverse at Ruby Gap locality, Madison County, Montana. See page 137 for explanation.

RUBY GAP

Terminal Point: SE 1/4, SW 1/4, NE 1/4, sec. 18, T. 9 S., R. 3 W., Home Park Ranch 7.5 minute quadrangle, Madison County, Montana. At base of large, overturned Quadrant cliff located on the north side of Upper Ruby River Road; about 500 feet above Canyon Campground, elevation about 6400 feet.

Thickness
in feet

QUADRANT FORMATION

Contact. - Phosphoria/Quadrant: gradational, contact arbitrarily placed where chert nodules become more prevalent in sandstones.

Upper Quartz Arenite Interval

14) Quartzite, cliff-former, pale yellowish brown (10YR 7/2), locally iron-stained, fine-grained, well-indurated, thickly bedded, relict cross-beds(?)......................76

13) Quartz arenite, calcite-cemented, ledge-former, yellowish gray (5Y 8/1), fine-grained, massive.................................16

12) Quartzite, ledge-former, very pale orange (10YR 8/2), heavily fractured, some surfaces display slickensides.....................6

/98

Lower Dolomitic Interval

11) Quartz arenite, dolomite-cemented, ledge-former, yellowish gray (5Y 7/2), fine-grained, locally bioturbated, crude medium-bedding with sporadic brown (5YR 3/2) chert pods and stringers (2 x 6")............7

10) Quartz arenite, silica-cemented, ledge-former, pale yellowish brown (10YR 7/2), massive..6

9) Quartz arenite, dolomite-cemented, subdued ledge-former, yellowish gray (5Y 7/2), fine-grained.....................................3

8) Quartz arenite, silica-cemented, ledge-former, yellowish gray (5Y 8/1), massive, heavily fractured.................................9

7) Siltstone, dolomite-cemented, poorly exposed, yellowish gray (5Y 7/2), localized chert pods (2 x 3")....................2

6) Alternating sequence of dolomite-cemented quartz arenites and dolostones; series of 2-3' ledge-formers, yellowish gray (5Y 8/1), medium-bedded, locally heavily fractured, contacts between the two lithologies are sharp................................20

5) Covered interval..................................60

4) Quartz arenites, silica-cemented, series of ledge-formers, yellowish gray (5Y 8/1), fine-grained, relict planar crossbeds(?), heavily fractured.......................35

3) Covered interval.................................109

2) Quartz arenite, calcite-cemented, subdued ledge-former, color ranging from light gray (N 7) to yellowish gray (5Y 8/1), fine-grained, heavily fractured..................13

1) Dolostone, subdued ledge-former, light olive gray (5Y 6/1), medium- to thick-bedded with unidentified fossil fragments, heavily fractured.................................8

TOTAL QUADRANT FORMATION...........................370

Contact. - Quadrant/unnamed limestone(?): poorly exposed, probably gradational.

Initial Point: SW 1/4, SW 1/4, NE 1/4, sec. 18, T. 9 S., R. 3 W., Home Park Ranch 7.5 minute quadrangle, Madison County, Montana. Just to the northeast of Upper Ruby River Road, elevation about 5920 feet. Section is poorly exposed.

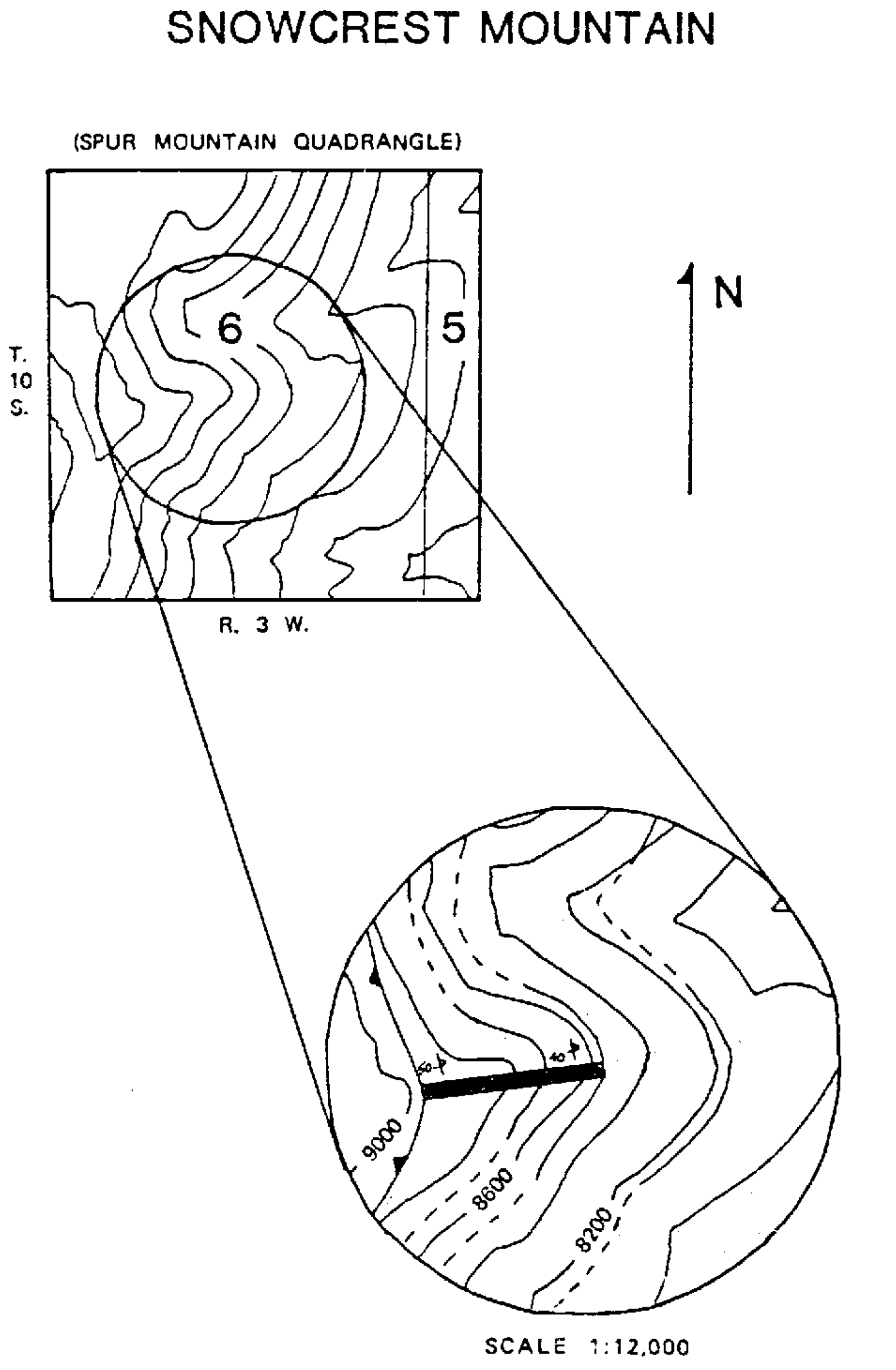

Figure 52. Bedrock geology and location of measured section transverse at Snowcrest Mountain, Snowcrest Range, Madison County, Montana. See page 137 for explanation.

SNOWCREST MOUNTAIN

Terminal Point: SW 1/4, SW 1/4, NE 1/4, sec. 6, T. 10 S., R. 3 W., Spur Mountain 7.5 minute quadrangle, Madison County, Montana. On a prominent ridge just to the south of the southern fork of Romy Creek at about 8600 feet; strata are overturned.

Thickness
in feet

QUADRANT FORMATION

Contact. - Phosphoria/Quadrant: covered by float, arbitrarily placed where chert nodules become more prevalent in sandstone float.

Upper Quartz Arenite Interval

26) Covered interval..................................23

25) Quartz arenite, dolomite-cemented, ledge-former, fine-grained, yellowish gray (5Y 6/1), locally surfaces mottled by iron-stained dots, bioturbated(?)......................13

24) Quartz arenite, calcite-cemented, ledge-former, well-indurated, fine-grained, very pale orange (10YR 8/2), massive..................14

23) Quartz arenite, both dolomite- and calcite-cemented, ledge-former, yellowish gray (5Y 8/1), fine-grained, porous. The unit is thickly bedded with individual laminae highlighted by iron staining..............8

22) Quartz arenite, calcite-cemented, subdued ledge-former, fine-grained, heavily iron-stained to grayish orange (10YR 7/4) color, massive, bioturbated(?)...................30

21) Quartz arenite, calcite-cemented, ledge-former, fine-grained, grayish orange (10 YR 7/4), thickly bedded..........................15

Lower Dolomitic Interval

20) Quartz arenite, dolomite-cemented, ledge-former, fine-grained, light gray (N 8). The unit is thinly bedded with planar cross-bed sets in the lower 2' and low angle (<10°) trough cross-beds in the upper 8'...................................10

19) Quartz arenites, both dolomite- and calcite-cemented, ledge-formers, fine-grained, very pale orange (10YR 8/2). The unit is thickly bedded with faint laminae highlighted by iron stains; locally fractured....46

18) Covered interval....................................20

17) Quartz arenite, dolomite-cemented, ledge-former, well-indurated, very pale orange (10YR 8/2). The unit is heavily fractured with many surfaces displaying slickensides.......18

16) Quartz arenites, dolomite-cemented, poorly exposed series of 2-3' ledges, fine-grained, yellowish gray (5Y 8/1), thinly bedded...31

15) Covered interval.....................................8

14) Quartz arenite, dolomite-cemented, ledge-former, very pale orange (10YR 8/2), locally iron-stained, fine-grained, medium-bedded......................................3

13) Covered interval.....................................6

TOTAL QUADRANT FORMATION.............................<u>245</u>

Contact. - Quadrant/unnamed limestone: poorly exposed, probably gradational.

LIMESTONE UNIT (unnamed) (incomplete)

12) Limestone, poorly exposed, recrystallized, very light gray (N 8), heavily fractured, brecciated...3

11) Covered interval....................................28

10) Quartz arenite, dolomite-cemented, subdued ledge-former, fine-grained, pinkish gray (5YR 8/1), thinly bedded with relict 6-8" cross-bed sets.............................12

9) Covered interval....................................56

8) Limestone ledges, poorly exposed, partially dolomitized, light brownish gray (5 YR 7/1), brecciated. The unit is thickly bedded with poorly preserved brachiopod(?) fragments. Locally, the unit is interbedded with a fine-grained dolomitic sandstone...48

7) Covered interval..................................8

6) Limestone, poorly exposed, partially dolomitized, light olive gray (5Y 6/1), heavily fractured, bioturbated(?).................6

5) Covered interval.................................38

4) Wackestones, subdued ledge-formers, color ranges from a light olive gray (5Y 6/1) to light gray (N 7). The unit is thickly bedded with localized chert stringers (6-10") oriented parallel to bedding, sparse brachiopod fragments......................14

3) Limestone ledges, poorly exposed, recrystallized, light olive gray (5Y 6/1), heavily fractured................................11

2) Covered interval, shales(?)......................63

1) Limestone, recrystallized, poorly exposed, light olive gray (5Y 6/1), thickly bedded(?)......5

TOTAL MEASURED PART OF LIMESTONE UNIT..............292

Contact: unnamed limestone/Lombard Limestone(?): thrust fault contact, poorly exposed.

Initial Point: SE 1/4, SE 1/4, NW 1/4, sec. 6, T. 10 S., R. 3 W., Spur Mountain 7.5 minute quadrangle, Madison County, Montana. On a prominent ridge just to the southwest of the headwaters for the southern fork of Romy Creek, elevation about 8920 feet. Strata are overturned and in thrust contact with Lombard Limestone(?).

SLIDEROCK MOUNTAIN

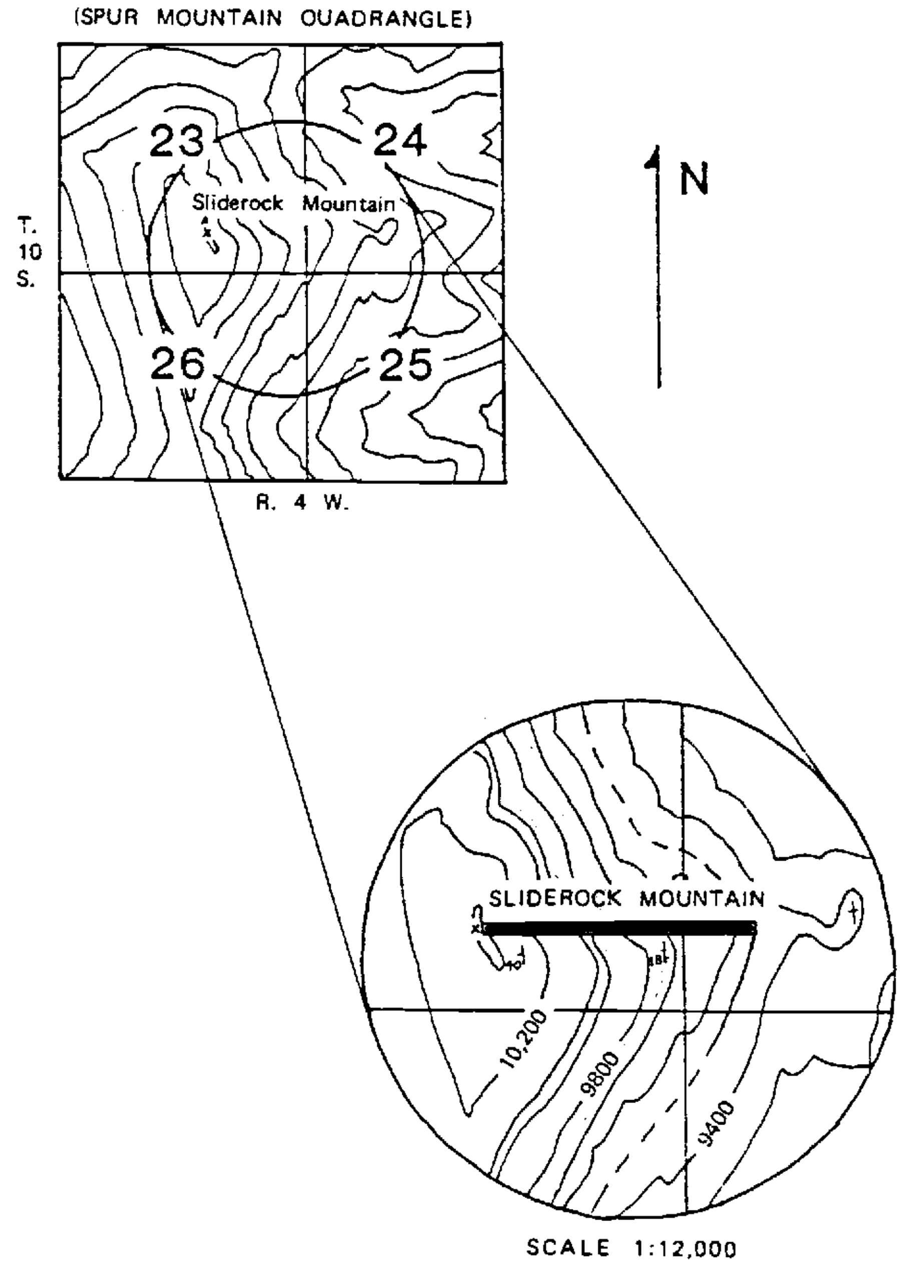

Figure 53. Bedrock geology and location of measured section transverse at Sliderock Mountain, Snowcrest Range, Madison County, Montana. See page 137 for explanation.

SLIDEROCK MOUNTAIN

Terminal Point: SW 1/4, SE 1/4, SE 1/4, sec. 23, T. 10 S., R. 4 W., Spur Mountain 7.5 minute quadrangle, Madison County, Montana. At the summit of Sliderock Mountain, elevation 10,439 feet.

Thickness
in feet

QUADRANT FORMATION (incomplete)

Upper Quartz Arenite Interval (incomplete)

53) Quartz arenites, locally dolomite-cemented, clean, fine-grained, well-sorted, resistant ledge-forming unit. Color ranges from a yellowish gray (5Y 8/1) to grayish orange pink (5YR 7/2) with sporadic iron-stained areas. The unit contains low-angle (<10°) trough and planar cross-bed sets............................220

Lower Dolomitic Interval

52) Dolostone, ledge-former, light olive gray (5Y 6/1), coarse-grained, sparkly texture, massive..................................15

51) Quartz arenite, dolomite-cemented, very fine-grained, well-indurated, ledge-former, very pale orange (10YR 8/2). Small scale (4-6") trough cross-bed sets; sinuous, symmetrical ripples on some surfaces...15

50) Dolostone, ledge-former, light olive gray (5Y 6/1), coarse-grained, sparkly texture, thinly bedded, chert stringers oriented parallel to bedding......................7

49) Talus covered interval. However, this interval could be observed on the steep cirque-wall face nearby and appears to consist of very thick-bedded quartz arenites and thin-bedded dolostones.............101

48) Dolostone, ledge-former, light brownish gray (5YR 6/1), coarse-grained, sparkly texture, massive.................................2

47) Quartz arenite, calcite-cemented, very fine-grained, well-indurated, ledge-former, color ranging from yellowish gray (5Y 7/2) to pale red (5Y 6/2). Massive, mottled on some surfaces, bioturbated............10

46) Poorly exposed sequence of alternating dolomite-cemented quartz arenites and dolostones. Quartz arenites: yellowish gray (5Y 8/1), very thickly bedded, faint laminae visible. Dolostones: light gray (N 7), thickly bedded, poorly preserved brachiopod(?) fragments. Most contacts betwwen two lithologies are sharp................48

45) Covered interval.................................15

44) Dolostone, ledge-former, very light gray (N 8), medium-bedded..............................16

43) Quartz arenite, dolomite-cemented, resistant ledge-former, very pale orange (10YR 8/2), thinly bedded, relict cross-beds(?)...6

42) Dolostone, ledge-former, light gray (N 7), coarse-grained, sparkly texture...................3

41) Quartz arenite, dolomite-cemented, moderately resistant, fine-grained, very pale orange (10YR 8/2), small (2 x 4") chert pods. Unit contains low angle trough and planar cross-bed sets with sporadic fossil fragments.................................15

40) Dolostone, subdued ledge-former, pinkish gray (5YR 8/1). Lower 4' are well-indurated, fine-grained, bioturbated(?) with poorly preserved brachiopod and crinoid(?) fragments; upper 2' are massive, coarse-grained, sparkly..................6

39) Poorly exposed dolostone(?).......................7

38) Dolostone, ledge-former, medium gray (N 5), coarse-grained, sparkly texture, intergranular porosity...........................12

37) Quartz arenite, dolomite-cemented, fine-grained, well-sorted, light brownish gray (5YR 7/1), massive................................7

36) Covered interval..................................2

35) Dolostone, ledge-former, fine-grained, medium gray (N 5), poorly preserved brachiopod(?) fragments..........................1

34) Quartz arenite, dolomite-cemented, fine-grained, yellowish gray (5Y 7/2), low-angle planar cross-beds..........................4

33) Dolostone, ledge-former, medium-grained, sparkly texture, intergranular porosity, medium light gray (N 6), massive..................5

32) Quartz arenite, dolomite-cemented, resistant ledge-former, light brownish gray (5YR 6/1)....................................5

31) Dolostone, fine-grained, light gray (N 7), mottled appearance with poorly preserved brachiopod(?) fragments, bioturbated.............11

30) Quartz arenite, dolomite-cemented, medium-grained, very pale orange (10YR 8/2), thinly bedded with irregular contacts between beds, locally scour-and-fill structures...3

29) Dolostone, ledge-former, fine-grained, medium light gray (N 6), massive, bioturbated, tracks and trails on lower surface, poorly preserved brachiopod fragments in concentrated zones................................5

28) Quartz arenite, dolomite-cemented, ledge-former, fine-grained, intergranular porosity, very pale orange (10YR 8/2), medium-bedded with low angle (<10°) cross-beds...12

TOTAL MEASURED PART OF QUADRANT FORMATION...........553

Contact. - Quadrant/unnamed limestone: gradational.

LIMESTONE UNIT (unnamed)

27) Mudstones, subdued ledge-formers, medium dark gray (N 4), sparsely fossiliferous with crinoid fragments, organic-rich, fetid odor upon fresh break, interbedded fissile shale partings [Geochem. samples GC-4 and GC-6]..................................27

26) Covered interval.................................25

25) Wackestone, poorly exposed, light gray (N 7), medium-bedded with localized brachiopod-crinoid concentrations oriented parallel to bedding................................8

24) Wackestone-packstone, ledge-formers, medium light gray (N 6), medium-bedded with isolated brachiopod packstones and fissile, organic-rich shale intervals............10

23) Quartz arenite, calcite-cemented, ledge-former, poorly sorted, light olive gray (5 Y 6/1), brachiopod(?) fragments randomly dispersed, scour-and-fill structures..............2

22) Wackestone, subdued ledge-former, light (N 7), fine-grained, massive, sparse crinoid and brachiopod fragments..........................4

21) Brachiopod packestones, series of ledges interbedded with shales, color ranges from a light brownish gray (5YR 7/1) to a light olive gray (5Y 6/1). The brachiopod packstones are thinly bedded with undulose contacts caused by dense concentrations of disarticulated Orthotetes kaskaskiensis bransonorum (brachiopod) shells aligned parallel to bedding...............................7

20) Wackestone, subdued ledge-former, medium light gray (N 6), brachiopod fragments randomly distributed, small brown chert pods...10

19) Poorly exposed interval, fissile shales..........46

18) Wackestone, subdued ledge-former, light gray (N 7), Composita cf. C. poposiensis (brachiopod) and crinoid fragments................4

17) Shales, slope-former, very light gray (N 8)..13

16) Encrinite, ledge-former, pale olive (10YR 6/2), coarse-grained, indistinct laminae defined by aligned brachiopod shells..............1

15) Wackestones, ledge-formers, light gray (N 7), medium-bedded with randomly dispersed Anthracospirifer welleri lincolnensis, Composita cf. C. poposiensis (brachiopods), and crinoid fragments, chert pods...10

14) Shales, slope-former, medium gray (N 5)..........23

13) Wackestone, subdued ledge-former, light olive gray (5Y 5/2), sparse crinoid, brachiopod, and bryozoan fragments, possibly bioturbated, small (2 x 5") chert pods..7

12) Mudstones, slope-former, pale olive (10Y 6/2), thinly laminated, rare brachiopod shells..2

11) Wackestones, series of 1-2' ledges separated by shales; brachiopod, crinoid, and unidentified species of Fenestellid and Trepostome bryozoa fragments; light olive gray (5Y 6/1), locally bioturbated.........23

10) Covered interval..................................9

9) Wackestone, subdued ledge-former, medium light gray (N 6), thinly bedded, brachiopod and crinoid fragments......................3

8) Wackestone, ledge-former, light brownish gray (5YR 7/1), medium-bedded, randomly dispersed brachiopod and crinoid fragments, locally small (2 x 4") chert pods.........18

7) Mudstone, subdued ledge-former, medium light gray (N 6), locally fossiliferous with crinoid and unidentified Orthotetid fragments, medium-bedded, locally organic-rich [Geochem. sample GC-5].....................10

TOTAL LIMESTONE UNIT..............................262

Contact. - unnamed limestone/Conover Ranch: poorly exposed, appears sharp.

CONOVER RANCH FORMATION

6) Poorly exposed interval. Red and gray shales, siltstones and isolated very fine-grained sandstone lenses.......................169

5) Mudstone, pale olive (10Y 6/2)...................4

4) Quartz arenite, calcite-cemented, very resistant cliff-former; color ranging from very pale orange (10YR 8/2) to light brown (5YR 5/6). The unit contains numerous truncated, low-angle (<10°) trough cross-bed sets, normally graded with local pebble-sized channel lag deposits. Cross laminations are highlighted by iron-staining. The unit is medium-grained with moderate sorting. Towards the bottom, the unit is slightly conglomeratic with imbricated clasts and wood fragments. The lower contact appears erosional to the subjacent unit..................35

3) Limestone conglomerate, partially exposed, pebble- to granule-sized clasts, pale yellowish brown (10YR 6/2), clasts range from well-rounded to angular and are slightly imbricated; heavily iron-stained sandstone matrix..................................5

2) Poorly exposed interval, red and gray shales and siltstones............................102

1) Quartz arenite, calcite-cemented, poorly exposed, yellowish gray (5Y 8/1), mottled by iron-stained dots, fine-grained...............10

TOTAL CONOVER RANCH FORMATION.......................325

Contact. - Conover Ranch/Lombard Limestone: poorly exposed, contact placed where limestone lithology gives way to a fine-grained sandstone lithology.

Initial Point: SW 1/4, SW 1/4, SW 1/4, sec. 24, T. 10 S., R. 4 W., Spur Mountain 7.5 minute quadrangle, Madison County, Montana. On the eastern flank of Sliderock Mountain, just to the south of a well-developed cirque; elevation about 9600 feet.

SPUR MOUNTAIN

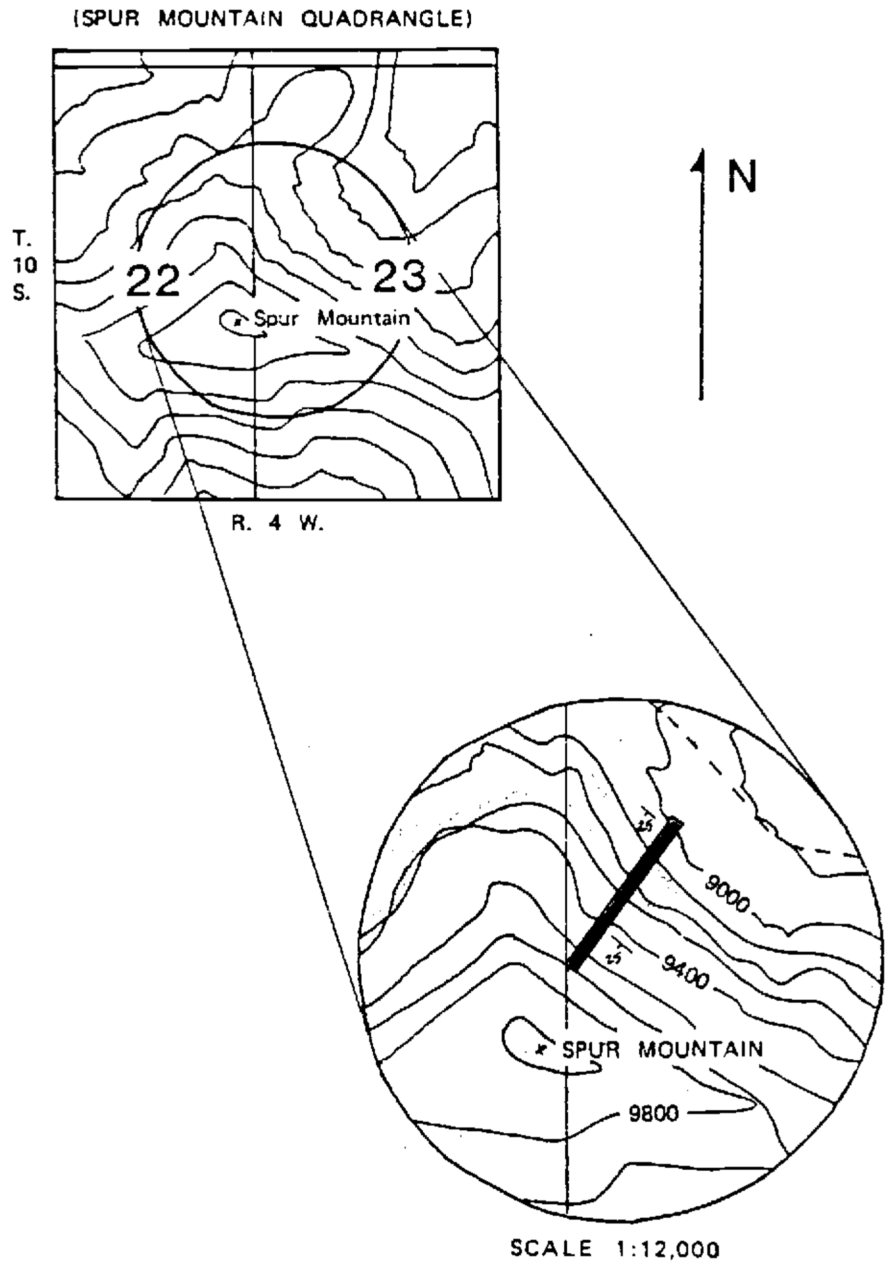

Figure 54. Bedrock geology and location of measured section transverse at Spur Mountain, Snowcrest Range, Madison County, Montana. See page 137 for explanation.

SPUR MOUNTAIN

Terminal Point: SW 1/4, SW 1/4, NW 1/4, sec. 23, T. 10 S., R. 4 W., Spur Mountain 7.5 minute quadrangle, Madison County, Montana. On northeastern flank of Spur Mountain, elevation about 9800 feet.

Thickness
in feet

QUADRANT FORMATION

Contact. - Phosphoria/Quadrant: gradational, contact arbitrarily placed where chert nodules become more prevalent in sandstones.

Upper Quartz Arenite Interval

45) Sandy dolostone, ledge-former, light olive gray (5Y 6/1), faint laminae, fossil traces, thickly bedded..........................35

44) Talus slope.......................................441

Lower Dolomitic Interval

43) Quartz arenite, dolomite-cemented, poorly exposed, fine-grained, yellowish gray (5Y 8/1), massive, bioturbated(?)....................65

42) Limestone, partially dolomitized, massive, light gray (N 7), poorly preserved brachiopods(?)....................................4

41) Quartz arenites, dolomite-cemented, ledge-formers, well-indurated, massive, yellowish gray (5Y 8/1), fine-grained..................49

40) Dolostone, ledge-former, massive, coarse-grained, sparkly texture, light olive gray (5Y 6/1)..10

39) Quartz arenite, dolomite-cemented, ledge-former, well-indurated, massive, fine-grained, yellowish gray (5Y 8/1).................21

38) Limestone, partially dolomitized, subdued ledge-former, light gray (N 7), thinly bedded with small (2 x 4") chert pods............15

640

37) Quartz arenite, dolomite-cemented, subdued ledge-former, yellowish gray (5Y 8/1), massive, fine-grained...........................16

36) Limestone, partially dolomitized, ledge-former, light gray (N 7), massive, fossil traces(?)..8

35) Quartz arenite, calcite-cemented, ledge-former, color ranges from very light gray (N 8) to yellowish gray (5Y 8/1), fine-grained, massive................................20

34) Dolostonè, subdued ledge-former, yellowish gray (5Y 8/1), poorly preserved brachiopods(?)....3

33) Wackestone, subdued ledge-former, medium light gray (N 6), medium-bedded with brachiopod fragments............................4

32) Quartz arenite, dolomite-cemented, ledge-former, light gray (N 7), massive, undulatory basal contact.........................12

31) Dolostone, ledge-former, light olive gray (5Y 6/1), massive, coarse-grained, sparkly texture...................................4

30) Quartz arenite, calcite-cemented, subdued ledge-former, very light gray (N 8), fine-grained, thinly bedded...........................5

TOTAL QUADRANT FORMATION............................<u>712</u>

Contact. - Quadrant/unnmaed limestone: gradational.

LIMESTONE UNIT (unnamed)

29) Wackestone, subdued ledge-former, light gray (N 7), medium-bedded with randomly dispersed brachiopod and crinoid fragments, locally small (2 x 5") chert pods..........6

28) Mudstones, subdued ledge-formers, medium gray (N 5), organic-rich, fetid odor upon fresh break. The unit is both blocky and fissile in habit, predominantly medium-bedded, locally small (2 x 3") chert pods [Geochem. sample GC-8].....................23

27) Covered interval.................................45

26) Wackestone, ledge-former, light olive gray (5Y 6/1), massive with brachiopod and crinoid fragments................................15

25) Covered interval.................................25

24) Wackestones, ledge-formers, light gray (N 7), interbedded with fissile shales. The unit contains randomly dispersed brachiopod and crinoid fragments and pale reddish brown (10R 5/4) chert pods (2 x 5")......30

23) Mudstone, poorly exposed, slope-former, light olive gray (5Y 6/1), thinly bedded..........5

22) Wackestones, ledge-formers, medium light gray (N 6), massive with brachiopod and crinoid fragments, locally thin-bedded brachiopod packstone intervals...................10

21) Shales, poorly exposed, light gray (N 7).........15

20) Wackestones, ledge-formers, light gray (N 7), thinly bedded with brachiopod and crinoid fragments, localized shale partings.......6

19) Wackestone, subdued ledge-former, medium light gray (N 6), thinly bedded with disarticulated brachiopod shells oriented parallel to bedding 8

18) Wackestone, ledge-former, color ranges from medium gray (N 5) to yellowish gray (5Y 8/1), massive with brachiopod and crinoid fragments.................................4

17) Shales, slope-former, light olive gray (5Y 6/1)..2

16) Wackestone, ledge-former, color ranging from light gray (N 7), to yellowish gray (5Y 8/1), medium-bedded with brachiopod and crinoid fragments, locally bioturbated. The unit also contains small (<1") oncolites..................................9

15) Covered interval..................................6

14) Wackestone, ledge-former, light gray (N 7), thinly bedded with crinoid and brachiopod fragments, locally a brachiopod packstone...4

13) Shales, slope-former, medium gray (N 5)..........13

12) Wackestones, ledge-formers, medium light gray (N 6), medium-bedded with randomly dispersed brachiopod and crinoid fragments and medium gray (N 5) chert pods (2 x 5"). The unit is locally a brachiopod packstone...4

11) Wackestone, ledge-former, light gray (N 7), massive with sparse brachiopod and crinoid fragments................................5

10) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), thinly bedded with brachiopod and crinoid fragments, interbedded shale partings.............................5

9) Wackestones/mudstones, ledge-formers, medium gray (N 5), medium-bedded with disarticulated brachiopod shells oriented parallel to bedding direction, localized scour-and-fill structures.......................11

8) Shales, slope-formers, yellowish gray (5Y 8/1)....6

7) Wackestones, ledge-formers, medium light gray (N 6), medium-bedded with randomly dispersed brachiopod and crinoid fragments, locally a brachiopod packstone............17

6) Covered interval..................................7

5) Wackestone, ledge-former, medium light gray (N 7), massive with sparse brachiopod fragments..4

4) Shales, slope-former, light gray (N 7), locally thin-bedded wackestone lenses............15

3) Wackestones, ledge-formers, medium light gray (N 6), medium- to thick-bedded with brachiopod and crinoid fragments; locally interbedded with organic-rich shales and thinly bedded, yellowish gray (5Y 8/1) brachiopod packstones [Geochem. sample GC-7].....30

TOTAL LIMESTONE UNIT...............................330

Contact. - unnamed limestone/Conover Ranch: poorly exposed, appears sharp.

CONOVER RANCH FORMATION (incomplete)

2) Covered interval................................200

1) Quartz arenite, calcite-cemented, ledge-former, very pale orange (10YR 8/2), medium-grained. The unit contains low angle (<10°), hematite-stained trough cross bed-sets, locally sets contain a basal pebble layer................................10

TOTAL MEASURED PART OF CONOVER RANCH FORMATION.....210

Initial Point: SW 1/4, NW 1/4, NW 1/4, sec. 23, T. 10 S., R. 4 W., Spur Mountain 7.5 minute quadrangle, Madison County, Montana. On northeastern flank of Spur Mountain, just to the southwest of a saddle separating Spring and Little Rock Creeks; elevation about 9160 feet.

HOGBACK MOUNTAIN

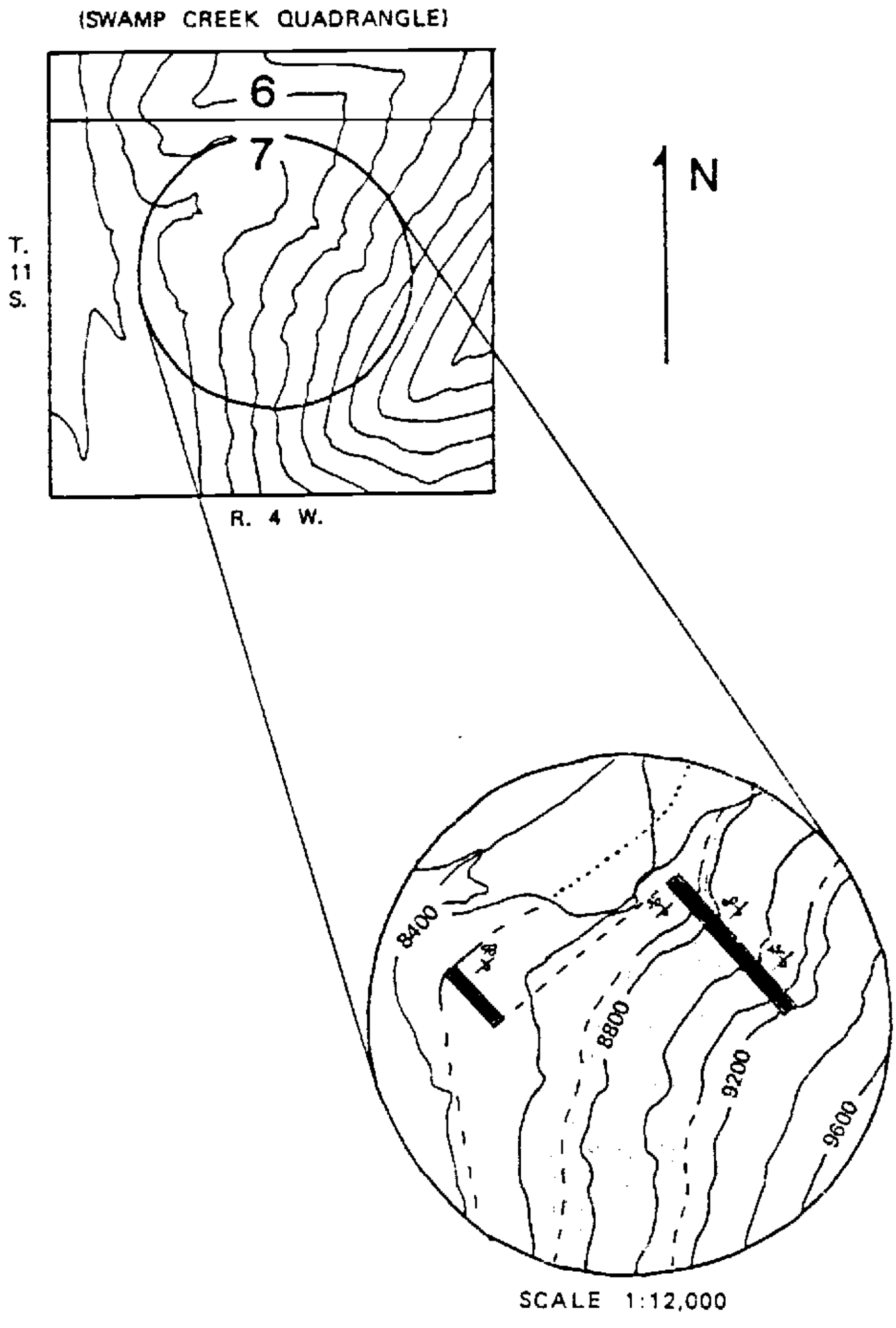

Figure 55. Bedrock geology and location of measured section transverse at Hogback Mountain, Snowcrest Range, Madison County, Montana. See page 137 for explanation.

HOGBACK MOUNTAIN

Terminal Point: NE 1/4, SW 1/4, NE 1/4, sec. 7, T. 11 S., R. 4 W., Swamp Creek 7.5 minute quadrangle, Madison County, Montana. On overturned, northwestern flank of Hogback Mountain; elevation about 9000 feet.

Thickness
in feet

QUADRANT FORMATION (incomplete)

Lower Dolomitic Interval (incomplete)

40) Quartz arenite, dolomite-cemented, ledge-former, yellowish gray (5Y 8/1), fine-grained, medium-bedded............................20

TOTAL MEASURED PART OF QUADRANT FORMATION............20

Contact. - Quadrant/unnamed limestone: gradational.

LIMESTONE UNIT (unnamed)

39) Wackestone, poorly exposed, partially dolomitized, light gray (N7), massive, poorly preserved brachiopod fragments............10

38) Brachiopod packstone, ledge-former, light olive gray (5Y 6/1), thinly bedded with disarticulated brachiopod shells aligned parallel to bedding direction.....................1

37) Bryozoan packstone, ledge-former, light gray (N7) to yellowish gray (5Y 8/1) with branching varieties of Trepostomata intertwinned together in growth position. The unit is lenticular in shape (3 x 15') and probably represents a small bioherm...........3

36) Wackestone, ledge-former, light gray (N7), massive with disarticulated brachiopod shells randomly oriented, lower 2' is mottled (bioturbated?).............................5

35) Covered interval.................................43

34) Limestone, poorly exposed, partially recrystallized, medium light gray (N6), localized shale partings containing disarticulated brachiopod shells.................30

33) Brachiopod packstones, subdued ledge-formers, color ranging from light brownish gray (5YR 6/1) to very pale orange (10YR 8/2), medium-bedded with disarticulated brachiopod shells aligned parallel to bedding, localized wackestone lenses.............15

32) Wackestone, ledge-former, light gray (N7), thickly bedded with randomly distributed brachiopod and crinoid fragments.................15

31) Wackestone, ledge-former, medium light gray (N6), thickly bedded with brachiopod and crinoid fragments; isolated bedding surfaces with ripples, tracks and trails, and mudcracks(?). The unit is interbedded with thinly bedded brachiopod packstones and organic-rich shales [Geochem. sample GC-1]..13

30) Wackestone, poorly exposed, light gray (N7), medium-bedded with brachiopod fragments, locally a brachiopod packstone........25

29) Covered interval.................................10

28) Brachiopod packstones, subdued ledge-formers, yellowish gray (5Y 8/1), thinly bedded with brachiopod fragments oriented parallel to bedding..............................4

27) Shales, slope-former, medium dark gray (N4), organic-rich, fetid odor upon fresh break...3

26) Quartz arenite, calcite-cemented, subdued ledge-former, dusky yellow (5Y 6/4), poorly sorted, localized scour-and-fill structures...1

25) Wackestone, subdued ledge-former, medium light gray (N6), medium-bedded with randomly distributed brachiopod and crinoid fragments, locally organic-rich mudstone intervals...............................31

24) Shale, poorly exposed, pale yellowish brown (10YR 6/2).................................8

23) Wackestone, ledge-former, light olive gray (5Y 6/1), thickly bedded with abundant brachiopod and crinoid fragments, brachiopod shells oriented parallel to bedding, locally a brachiopod packstone..................12

22) Shale, poorly exposed, very pale orange (10YR 8/2) 8

21) Wackestone, ledge-former, light gray (N7), medium-bedded with randomly distributed brachiopod and crinoid fragments..................7

20) Covered interval..................................15

19) Wackestones, series of 3' ledges, medium light gray (N6), poorly indurated, medium-bedded with randomly dispersed brachiopod fragments and olive gray (5Y 4/1) chert pods (3 x 5"), locally bioturbated...............22

18) Mudstones, slope-former, medium dark gray (N4), platy habit, organic-rich, fetid odor upon fresh break, sparse brachiopod fragments [Geochem. sample GC-3].................29

17) Wackestones, series of 4' ledges, light olive gray (5Y 6/1), thickly bedded with brachiopod and crinoid fragments, localized shale partings.........................22

16) Covered interval..................................21

15) Wackestone, ledge-former, olive gray (5Y 4/1), thinly bedded with crinoid, brachiopod, and bryozoa fragments, locally dark gray (N3) chert pods (2 x 4"). The unit is interbedded with organic-rich shales [Geochem. sample GC-2]............................5

14) Covered interval...................................9

13) Limestone, recrystallized, subdued ledge-former, medium light gray (N6), massive, heavily fractured................................13

TOTAL LIMESTONE UNIT.................................380

Contact. - unnamed limestone/Conover Ranch: covered.

CONOVER RANCH FORMATION

12) Covered interval.................................100

11) Siltstones, calcareous, poorly exposed, color ranging from yellowish brown (10YR 5/2) to yellowish gray (5Y 7/2), faint laminations(?)...................................40

10) Quartz arenite, calcite-cemented, very fine-grained, subdued ledge-former, pale brown (5YR 5/2), bioturbated, calcite vugs, faint cross-laminations highlighted by iron-staining................................5

9) Mudstone, poorly exposed, yellowish gray (5Y 7/2)..7

8) Siltstones, calcareous, poorly exposed, medium reddish brown (10R 4/4), calcite vugs, thinly bedded(?)............................4

7) Quartz arenite, calcite-cemented, fine-grained, poorly exposed, light olive gray (5Y 6/1), calcite vugs, thinly bedded............10

6) Covered interval.................................30

5) Siltstones, calcareous, poorly exposed, medium reddish brown (10R 4/4), calcite vugs..5

4) Covered interval.................................53

3) Limestone conglomerate, pebble-sized clasts, ledge-former, light bluish gray (5B 7/1), locally iron-stained. The unit is medium-bedded with interbedded yellowish gray (5Y 8/1) quartz arenite lenses (3 x 9"). In general, the unit fines upward from a pebble limestone conglomerate to a coarse-grained quartz arenite (grainstone?)............................9

2) Covered interval.................................76

1) Quartz arenite, calcite-cemented, subdued ledge-former, yellowish gray (5Y 7/2), fine-grained, medium-bedded with planar cross-bed sets..................................20

TOTAL CONOVER RANCH FORMATION......................359

Contact. - Conover Ranch/Lombard Limestone: sharp, locally erosional(?).

Initial Point: NW 1/4, SE 1/4, NW 1/4, sec. 7, T. 11 S., R. 4 W., Swamp Creek 7.5 minute quadrangle, Madison County, Montana. On overturned, northwestern flank of Hogback Mountain. Initial point begins on a small knoll where sandstones of the Conover Ranch Formation are exposed; elevation about 8520 feet.

SUNSET PEAK

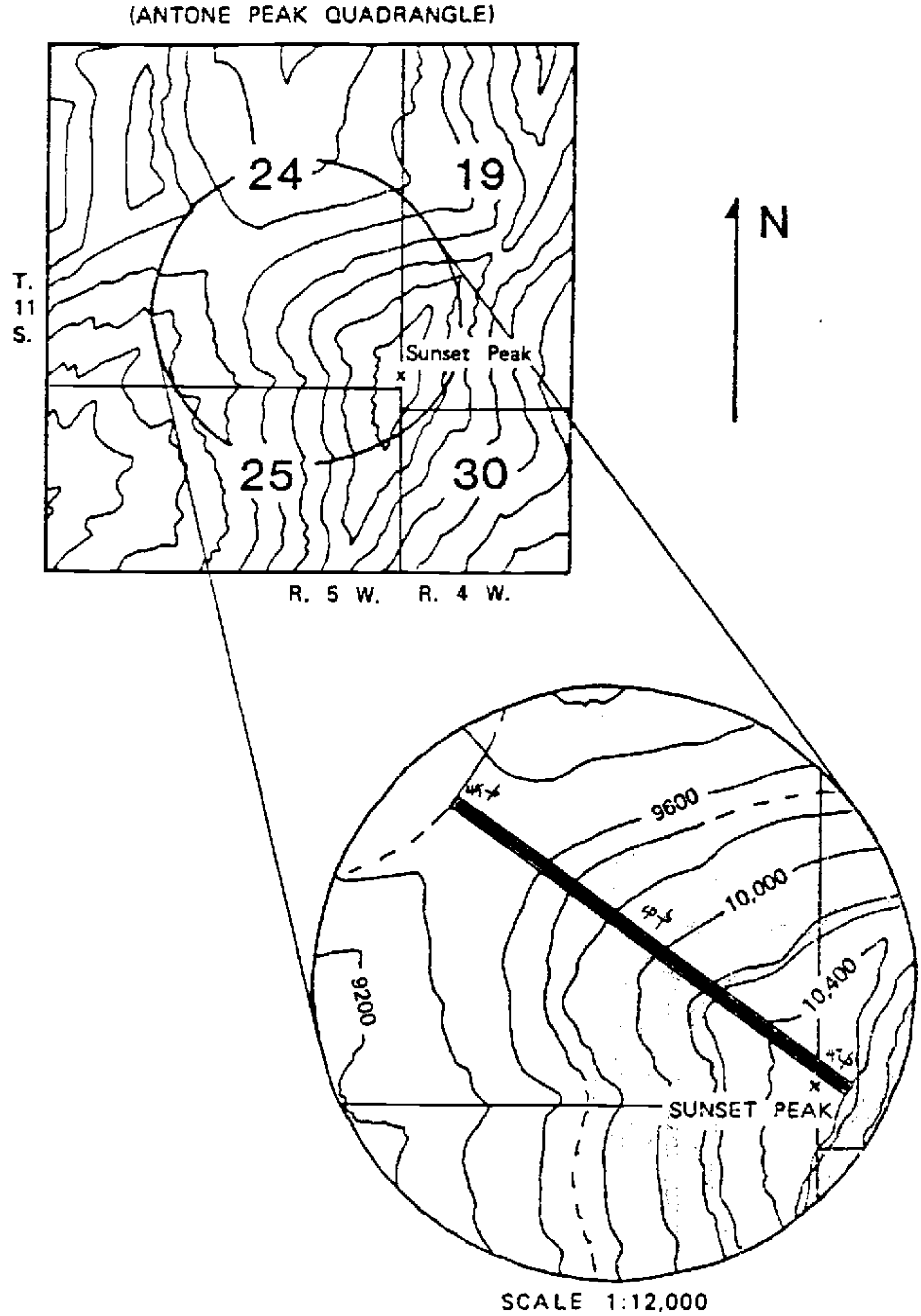

Figure 56. Bedrock geology and location of measured section transverse at Sunset Peak, Snowcrest Range, Madison County, Montana. See page 137 for explanation.

SUNSET PEAK

Terminal Point: SW 1/4, SW 1/4, SW 1/4, sec. 19, T. 11 S., R. 4 W., Antone Peak 7.5 minute quadrangle, Madison County, Montana. On eastern flank of Sunset Peak, just below the summit; elevation about 10.550 feet.

Thickness
in feet

QUADRANT FORMATION

Contact. - Phosphoria/Quadrant: Cocealed by talus, arbitrarily placed where chert nodules become more prevalent in sandstone float.

Upper Quartz Arenite Interval

45) Quartz arenite, silica-cemented, cliff-former, color ranging from very light gray (N8) to yellowish gray (5Y 8/1). The unit is fine-grained, thickly bedded and contains large (1-2') trough cross-bed sets.....110

44) Quartz arenite, calcite-cemented, series of resistant ledge-formers, very pale orange (10YR 8/2), fine-grained, massive to thickly bedded, locally dolomite-cemented....101

Lower Dolomitic Interval

43) Quartz arenite, dolomite-cemented, ledge-former, yellowish gray (5Y 7/2), fine-grained, massive....................................8

42) Alternating sequence of dolomite- and calcite-cemented quartz arenites, series of 2-3' ledge-formers. The unit is fine-grained, locally cross-bedded, and ranges in color from very pale orange (10YR 8/2) to yellowish gray (5Y 8/1).......................88

41) Wackestone, subdued ledge-former, medium light gray (N6), thin- to medium-bedded with brachiopod and crinoid fragments, subtle rippled surfaces, locally small (2 x 3") chert pods................................14

40) Dolostone, subdued ledge-former, light olive gray (5Y 7/1), massive.....................21

39) Mudstone, poorly exposed, yellowish gray (5Y 8/1)..10

38) Quartz arenite, dolomite-cemented, ledge-former, very pale orange (10YR 8/2), fine-grained, massive..................................10

TOTAL QUADRANT FORMATION..............................362

Contact. - Quadrant/unnamed limestone: gradational, poorly exposed.

LIMESTONE UNIT (unnamed)

37) Wackestone, poorly exposed series of 3-4' ledges, light olive gray (5Y 6/1), medium-bedded with brachiopod and crinoid fragments, locally tracks and trails on lower bedding surfaces............................32

36) Quartz arenite, dolomite-cemented, ledge-former, yellowish gray (5Y 6/1), fine-grained, massive..................................15

35) Recrystallized limestone, poorly exposed, light olive gray (5Y 6/1), heavily fractured with numerous calcite veins............63

34) Quartz arenite, dolomite-cemented, ledge-former, yellowish gray (5Y 7/2), fine-grained, massive..................................12

33) Wackestone, subdued ledge-former, light gray (N7), medium-bedded with brachiopod fragments, tracks and trails on some bedding surfaces, localized small (2 x 4") chert pods..12

32) Covered interval...................................7

31) Quartz arenite, calcite-cemented, ledge-former, very pale orange (10YR 8/2), fine-grained, massive..................................9

30) Covered interval..................................14

29) Wackestone, poorly exposed, yellowish gray (5Y 8/1), thin- to medium-bedded with brachiopod fragments.............................20

28) Quartz arenite, dolomite-cemented, ledge-former, very pale orange (10YR 8/2), fine-grained...2

27) Mudstone, poorly exposed, light olive gray (5Y 6/1), sparse crinoid fragments...............33

26) Wackestones, subdued ledge-formers, light gray (N7), medium-bedded with brachiopod and crinoid fragments, locally a brachiopod packstone.................................19

25) Brachiopod packstones, series of subdued ledge-formers, light olive gray (5Y 6/1), thinly bedded with undulose contacts caused by dense concentrations of disarticulated brachiopod shells aligned parallel to bedding, interbedded shale partings.......................................36

24) Wackestone, ledge-former, light olive gray (5Y 6/1), medium-bedded with brachiopod and crinoid fragments, locally a brachiopod packstone.................................11

23) Wackestones, series of subdued ledge-formers, yellowish gray (5Y 7/1), medium-bedded with Anthracospirifer aff. A. occiduus (brachiopod), crinoid, and bryozoa fragments, localized chert stringers (4-6") oriented parallel to bedding....23

22) Covered interval.................................14

21) Wackestone, ledge-former, light brownish gray (5YR 6/1), brachiopod and crinoid fragments, massive, thin (1/16") calcite veins..2

20) Covered interval.................................17

19) Wackestone, ledge-former, light olive gray (5Y 6/1), medium-bedded with brachiopod and crinoid fragments, localized brachiopod packstone intervals........................3

18) Covered interval..................................3

17) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), brachiopod, crinoid, and bryozoa fragments............................1

16) Covered interval.................................18

15) Wackestone, ledge-former, medium dark gray (N4), medium-bedded with brachiopod, crinoid, and bryozoa fragments. The unit is interbedded with organic-rich shales [Geochem. sample GC-9].........................10

14) Covered interval.................................21

13) Wackestones, series of ledge-formers, light gray (N7), thin- to medium-bedded with brachiopod and crinoid fragments, localized dark gray (N3) small (2 x 3") chert pods. Encrinite layers characterize the basal parts of many ledges..................23

12) Covered interval.................................20

11) Wackestone, ledge-former, yellowish gray (5Y 8/1), medium-bedded with brachiopod and crinoid fragments, locally a moldic porosity...15

10) Covered interval.................................46

9) Wackestone, subdued ledge-former, medium olive gray (5Y 5/1), thinly bedded with brachiopod, crinoid, and bryozoa fragments. The unit is fractured by thin (1/16") calcite veins.............................7

TOTAL LIMESTONE UNIT...............................508

Contact. - unnamed limestone/Conover Ranch: poorly exposed, appears sharp.

CONOVER RANCH FORMATION

8) Covered interval.................................88

7) Shale/siltstone interval, poorly exposed, yellowish gray (5Y 8/1)..........................24

6) Quartz arenites, calcite-cemented, ledge-formers, light olive gray (5Y 7/1), locally hematite stained. The unit contains low angle (<5°) trough cross-bed sets and is interbedded locally with grainstone and pebble limestone conglomerate lenses (6 x 18")............................25

5) Alternating sequence of calcite-cemented quartz arenites and pebble- to cobble-sized limestone conglomerates. Quartz arenites: yellowish gray (5Y 8/1), trough cross-bedded, fine-grained, locally a grainstone; limestone conglomerates: grayish orange (10YR 7/4), crudely cross-bedded, hematite-stained, limestone clasts are rounded and contain _Siphonophyllia_ sp. (coral), brachiopod, and crinoid fragments. The conglomerate is interbedded with (3 x 8") grainstone lenses.................22

4) Covered interval..................................28

3) Grainstone, ledge-former, color ranging from yellowish gray (5Y 8/1) to grayish orange (10YR 7/4), faint cross-bedded intervals, locally interbedded with pebble limestone conglomerate lenses (4 x 12") which contain wood fragments.....................10

2) Covered interval..................................51

1) Grainstone, ledge-former, light bluish gray (5B 6/1), locally cross-bedded with basal pebble limestone conglomerate layers, hematite-stained..........................2

TOTAL CONOVER RANCH FORMATION......................250

Contact. - Conover Ranch/Lombard Limestone: sharp, slightly undulating, locally erosional.

Initial Point: SW 1/4, NW 1/4, SE 1/4, sec. 24, T. 11 S., R. 5 W., Antone Peak 7.5 minute quadrangle, Madison County, Montana. On northern side of saddle separating Crows Nest and Robb Creeks on northwestern flank of Sunset Peak; elevation about 9480 feet.

SAWTOOTH MOUNTAIN

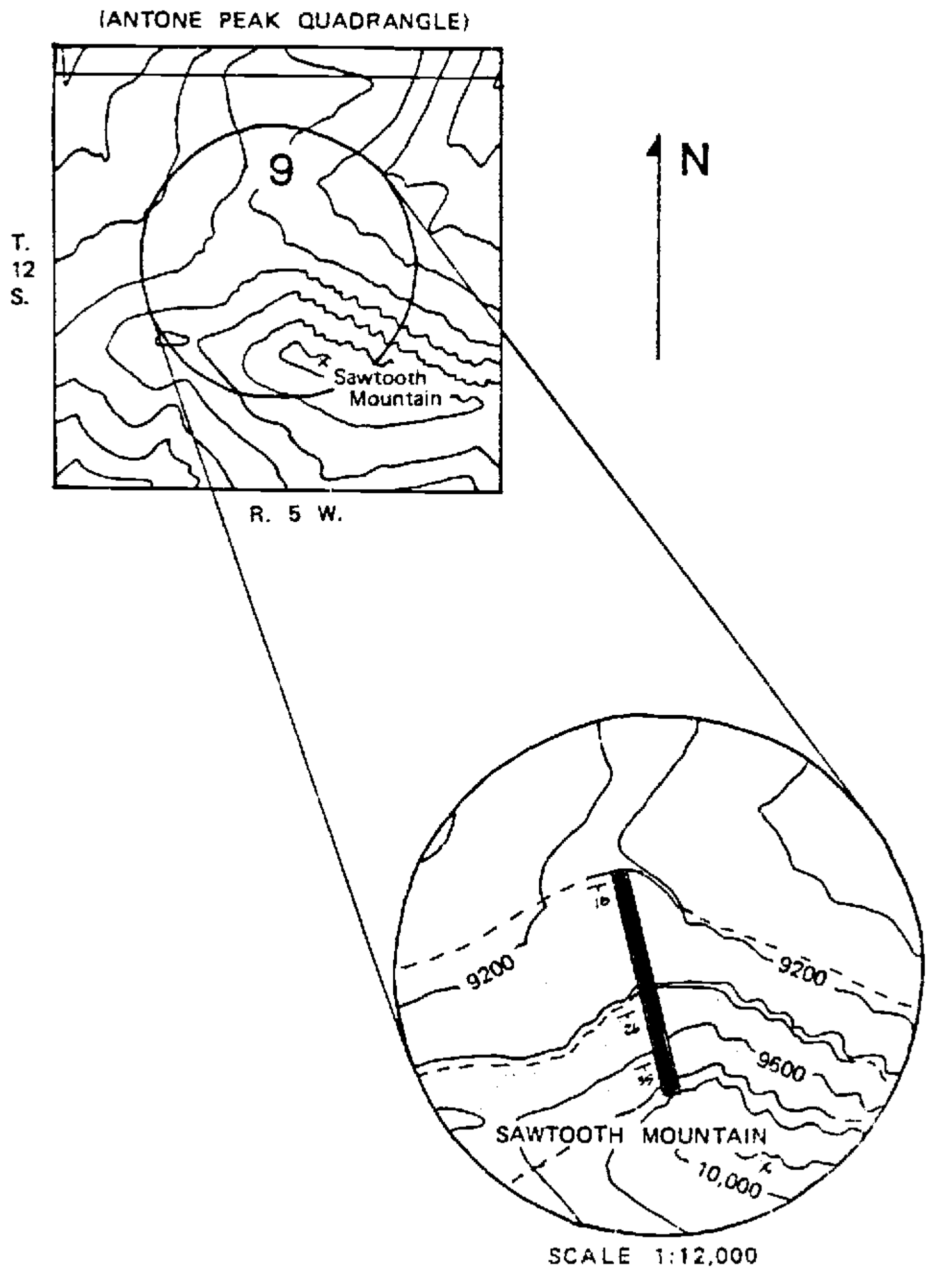

Figure 57. Bedrock geology and location of measured section transverse at Sawtooth Mountain, Snowcrest Range, Beaverhead County, Montana. See page 137 for explanation.

SAWTOOTH MOUNTAIN

Terminal Point: NE 1/4, NE 1/4, SW 1/4, sec. 9, T. 12 S., R. 5 W., Antone Peak 7.5 minute quadrangle, Beaverhead County, Montana. On northern flank of Sawtooth Mountain, just to the west of steep north-facing cliffs of Sawtooth Mountain; elevation about 9850 feet.

Thickness
<u>in feet</u>

QUADRANT FORMATION (incomplete)

Lower Dolomitic Interval (incomplete)

34) Alternating sequence of dolomite-cemented quartz arenites and dolostones, series of 3' ledge-formers. Quartz arenites: grayish orange (10YR 7/4), fine-grained, thickly bedded; dolostones: very pale orange (10YR 8/2), medium-bedded........................60

33) Quartz arenite, dolomite-cemented, ledge-former, grayish orange (10YR 7/4), fine-grained...10

TOTAL MEASURED PART OF QUADRANT FORMATION............<u>70</u>

Contact. - Quadrant/unnamed limestone: gradational.

LIMESTONE UNIT (unnamed)

32) Alternating sequence of wackestones and mudstones, moderately exposed 1' ledge-formers, color ranging from yellowish gray (5Y 8/1) to light olive gray (5Y 6/1), thin- to medium-bedded with randomly dispersed brachiopod and crinoid fragments.......18

31) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), brachiopod and crinoid fragments...............................7

30) Brachiopod packstones, series of subdued ledge-formers interbedded with fissile shales, yellowish gray (5Y 8/1). The brachiopod packstones are thinly bedded with undulose contacts caused by dense concentrations of disarticulated brachiopod shells aligned parallel to bedding. Locally interbedded with Trepostome and Cystoporid bryozoans, small bioherms(?)..........12

29) Recrystallized limestone, poorly exposed, light gray (N7), massive, brecciated.............14

28) Mudstone, slope-former, light olive gray (5Y 6/1), thinly laminated, isolated chert pods and brachiopod fragments....................4

27) Wackestones, subdued ledge-formers, yellowish gray (5Y 8/1), medium-bedded with brachiopod and crinoid fragments............21

26) Mudstones, subdued ledge-formers, olive black (5Y 2/1), sparsely fossiliferous with crinoid and Orbiculoidea cf. O. wyomingensis (brachiopd) fragments, organic-rich, fetid odor upon fresh break, thin- to medium-bedded [Geochem. sample GC-10].....................................8

25) Wackestone, ledge-former, light olive gray (5Y 6/1), medium-bedded with brachiopod and crinoid fragments, locally a brach-iopod packstone.................................10

24) Shale, poorly exposed, medium gray (N5)...........2

23) Wackestones, ledge-formers, light olive gray (5Y 6/1), medium-bedded with randomly distributed brachiopod and crinoid fragments, localized shale partings..............13

22) Recrystallized limestone, subdued ledge-former, medium light gray (N6), massive with unidentified fossil fragments................4

21) Covered interval.................................40

20) Wackestone, ledge-former, yellowish gray (5Y 7/2), thinly bedded with 1" chert pods and randomly distributed brachiopod and crinoid fragments.................................9

19) Covered interval.................................36

18) Wackestones, series of ledge-formers, yellowish gray (5Y 8/1), medium-bedded with brachiopod, crinoid, and bryozoa fragments, interbedded with shale partings.......25

17) Covered interval.................................19

16) Wackestone, ledge-former, very light gray (N8), brachiopods oriented parallel to bedding...2

15) Wackestone, poorly exposed, light brownish gray (5YR 6/1), crinoid and Orthotetes cf. O. kaskaskiensis bransonorum(?) (brachiopod) fragments randomly dispersed, localized (2 x 4") chert pods....................17

14) Wackestones/packstones, ledge-formers, light olive gray (5Y 6/1), thin- to medium-bedded with brachiopod and crinoid fragments. The brachiopod packstones have undulose contacts caused by dense concentration of disarticulated brachiopod shells aligned parallel to bedding...............14

13) Wackestone, subdued ledge-former, yellowish gray (5Y 8/1), medium-bedded with brachiopod and crinoid fragments.................13

12) Recrystallized limestone, poorly exposed, olive gray (5Y 4/1), brecciated, 3" chert stringers...7

11) Wackestone, ledge-former, light brownish gray (5YR 6/1), massive with brachiopod and crinoid fragments............................3

10) Wackestone, subdued ledge-former, light brownish gray (5YR 6/1), medium-bedded with crinoid fragments, interbedded with shale partings, localized dark gray (N3), 2-4" chert stringers.......................11

9) Recrystallized limestone, ledge-former, olive gray (5Y 4/1), massive, isolated brachiopod fragments, brecciated with numerous calcite veins..........................21

8) Wackestone, ledge-former, color ranging from light brownish gray (5YR 6/1) to light olive gray (5Y 6/1), medium-bedded with brachiopod and crinoid fragments, locally a brachiopod packstone..................11

7) Covered interval.................................22

6) Wackestone, ledge-former, olive gray (5Y 4/1), massive, heavily fractured with numerous calcite veins, randomly dispersed brachiopod and crinoid fragments.................13

TOTAL LIMESTONE UNIT...............................376

Contact. - unnamed limestone/Conover Ranch: poorly exposed, appears sharp.

CONOVER RANCH FORMATION

5) Covered interval..................................87

4) Quartz arenite, calcite-cemented, ledge-former, yellowish gray (5Y 8/1), fine-grained, moderately sorted. The unit contains numerous truncated, low angle (<10°) trough cross-bed sets that are normally graded, some sets contain basal pebble layers. Cross laminations are highlighted by hematite stains. The unit is intercalated with thin (3 x 12") mudstone lenses. The lower contact of the unit appears erosional to the subjacent limestone conglomerate..........................15

3) Limestone conglomerate, ledge-former, color ranging from light olive gray (5Y 6/1) to light brown (5YR 5/6). Limestone clasts are typically cobble-sized, well-rounded, and contain poorly preserved brachiopod and crinoid fragments. The unit is crudely cross-bedded with localized (4 x 10") sandstone lenses.......................10

2) Covered interval, shales and mudstones(?).......213

1) Quartz arenites, calcite-cemented, ledge-formers, color ranging from olive gray (5Y 4/1) to yellowish gray (5Y 8/1). The unit is well-indurated, fine-grained, moderately sorted and displays low angle trough and planar cross-bed sets. Cross laminations are locally highlighted by hematite staining. An undulating, slightly erosional contact characterizes the lowermost stratum of this unit to the subjacent Lombard Limestone......................46

TOTAL CONOVER RANCH FORMATION......................371

Contact. - Conover Ranch/ Lombard Limestone: Excellent exposure of contact. The contact is sharp, broadly undulating with scour-and-fill structures. Relief along the contact is up to three inches. Locally, Lombard Limestone rip-up clasts can be observed on the lowermost surfaces of the Conover Ranch sandstones.

Initial Point: NE 1/4, SE 1/4, NW 1/4, sec. 9, T. 12 S., R. 5 W., Antone Peak 7.5 minute quadrangle, Beaverhead County, Montana. On the northern flank of Sawtooth Mountain, just to the southeast of a saddle along the "Sawtooth Trail"; elevation about 9200 feet.

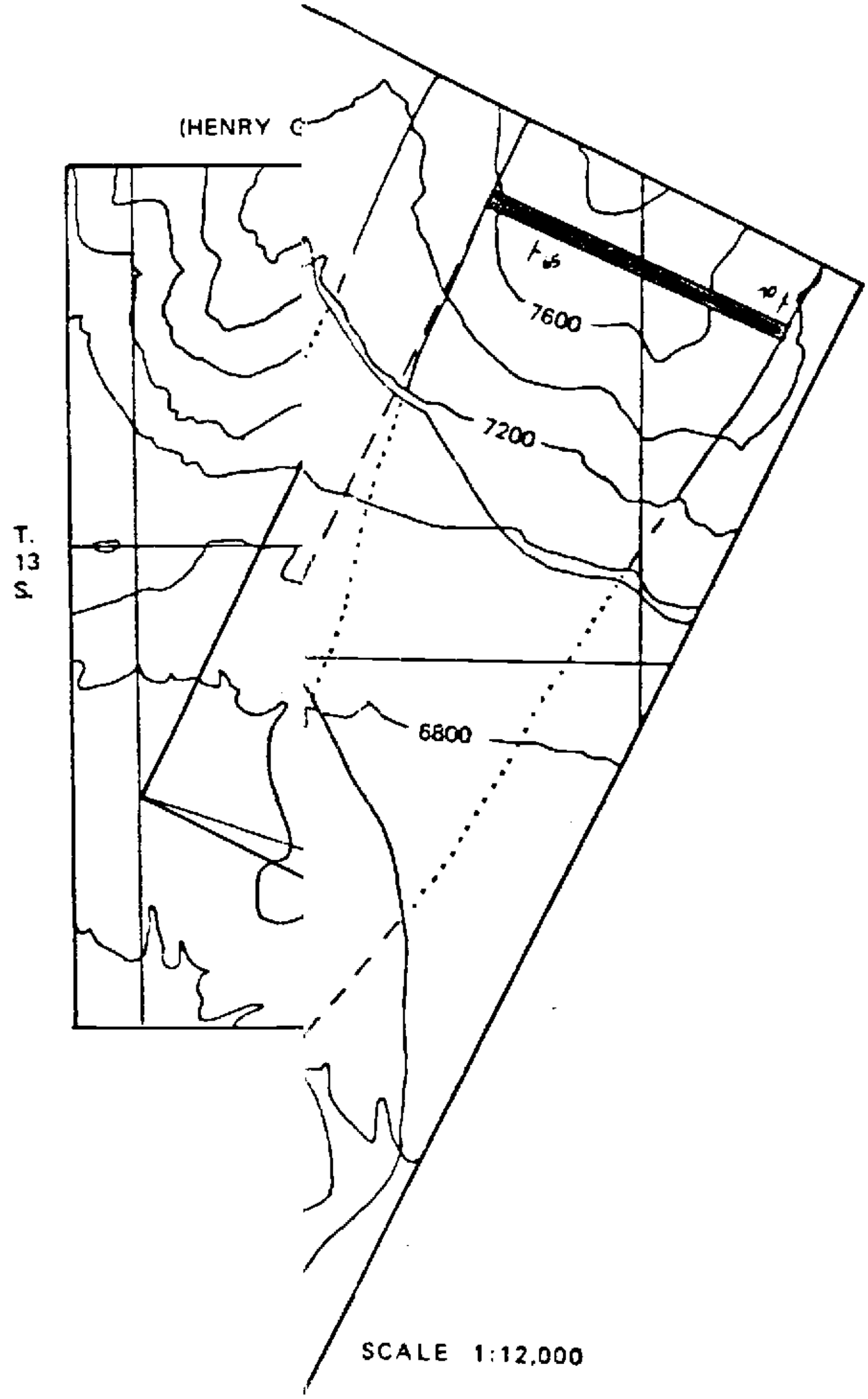

Figure 58. Bed
Rock River
137 for ex

RED ROCK RIVER

Terminal Point: SE 1/4, Nw 1/4, SW 1/4, sec. 22, T. 13 S., R. 7 W., Henry Gulch 7.5 minute quadrangle, Beaverhead County, Montana. On prominent ridge about two miles to the north of Lima Reservoir Road; elevation about 7400 feet.

Thickness
in feet

QUADRANT FORMATION

Contact. - Phosphoria/Quadrant: gradational, contact is arbitrarily placed where chert nodules become more prevalent in sandstones.

39) Quartz arenite, calcite-cemented, ledge-former, light gray (N7), fine-grained, well-indurated, medium-bedded....................12

38) Covered interval..................................8

37) Quartz arenite, silica-cemented, series of ledge-formers, yellowish gray (5Y 7/2), fine-grained, fair porosity, friable, localized heavy mineral layers..................100

36) Quartz arenites, silica-cemented, ledge-formers, dark yellowish orange (10YR 6/6), fine-grained, well-indurated, relict medium-bedding..................................74

35) Covered interval................................294

34) Quartz arenites, silica-cemented, partially exposed sequence within a talus field, color ranging from yellowish gray (5Y 8/1) to light brown (5YR 5/6), fine-grained, medium-bedded, many surfaces display slickensides.................................413

TOTAL QUADRANT FORMATION............................901

Contact. - Quadrant/unnamed limestone: poorly exposed, probably gradational.

LIMESTONE UNIT (unnamed)

33) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), thinly bedded with brachiopod and crinoid fragments.................12

32) Covered interval................................59

31) Wackestone, subdued ledge-former, light gray (N3), 5" chert stringers....................8

30) Covered interval.................................51

29) Wackestones, series of subdued ledge-formers, light olive gray (5Y 6/1), thinly bedded with brachiopod and crinoid fragments, locally becoming a brachiopod packstone. The unit is interbedded with shaly intervals..................................49

28) Covered interval.................................21

27) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), thinly bedded with crinoid fragments................................4

26) Covered interval.................................7

25) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), thinly bedded with crinoid fragments................................6

24) Mudstones, poorly exposed slope-former, yellowish gray (5Y 6/1)..........................15

23) Covered interval.................................8

22) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), thinly bedded with brachiopod and crinoid fragments, localized 5" chert stringers...........................3

21) Mudstones, poorly exposed slope-former, yellowish gray (5Y 8/1)..........................19

20) Wackestone, ledge-former, light olive gray (5Y 6/1), medium-bedded with crinoid fragments, locally an encrinite......................5

19) Covered interval.................................23

18) Wackestones, subdued ledge-formers, olive gray (5Y 4/1), medium-bedded with brachiopod and crinoid fragments, locally heavily fractured..11

17) Covered interval.................................16

16) Wackestone, ledge-former, light olive gray (5Y 6/1), thinly bedded with brachiopod and crinoid fragments............................5

15) Mudstone, poorly exposed slope-former, yellowish gray (5Y 8/1), localized wackestone lenses..................................7

14) Wackestone, ledge-former, light olive gray (5Y 6/1), thinly bedded with brachiopod and crinoid fragments..............................2

13) Covered interval..................................2

12) Wackestone, subdued ledge-former, olive gray (5Y 4/1), medium-bedded with brachiopod and crinoid fragments, localized 4" chert pods......................................2

11) Wackestone, ledge-former, olive gray (5Y 4/1), medium-bedded with brachiopod, crinoid, and coral(?) fragments...................2

10) Mudstone, poorly exposed slope-former, light olive gray (5Y 6/1)..........................7

9) Wackestone, subdued ledge-former, yellowish gray (5Y 8/1), medium-bedded with brachiopod and crinoid fragments, concentrated fossil layer at the base.............5

8) Covered interval..................................6

7) Wackestone, subdued ledge-former, light olive gray (5Y 6/1), thinly bedded with brachiopod fragments, localized 3" chert pods...2

6) Covered interval..................................5

5) Wackestone, ledge-former, light gray (N7), thinly bedded with brachiopod and crinoid fragments.......................................2

4) Recrystallized limestone, subdued ledge-former, light brownish gray (5YR 7/1), massive..3

3) Wackestone, ledge-former, color ranging from dark yellowish brown (10YR 4/2) to yellowish gray (5Y 8/1). The unit is medium-bedded with brachiopod and crinoid fragments, localized encrinite lenses (3 x 6")....2

TOTAL LIMESTONE UNIT..............................369

Contact. - unnamed limestone/Conover Ranch: concealed.

CONOVER RANCH FORMATION

2) Covered interval, shale(?).......................598

1) Quartz arenite, calcite-cemented, poorly exposed, grayish orange (10YR 7/4), surface of unit speckled by hematite-stained dots, fine-grained, friable..............40

TOTAL CONOVER RANCH FORMATION.......................638

Contact. - Conover Ranch/Lombard Limestone: poorly exposed, contact is arbitrarily placed where sandstone/siltstone float gives way to limestone float.

Initial Point: NW 1/4, NE 1/4, SW 1/4, sec. 28, T. 13 S., R. 7 W., Henry Gulch 7.5 minute quadrangle, Beaverhead County, Montana. On a subdued knoll about one-half mile north of the Lima Reservoir Road; elevation about 6550 feet.

BIG SHEEP CREEK

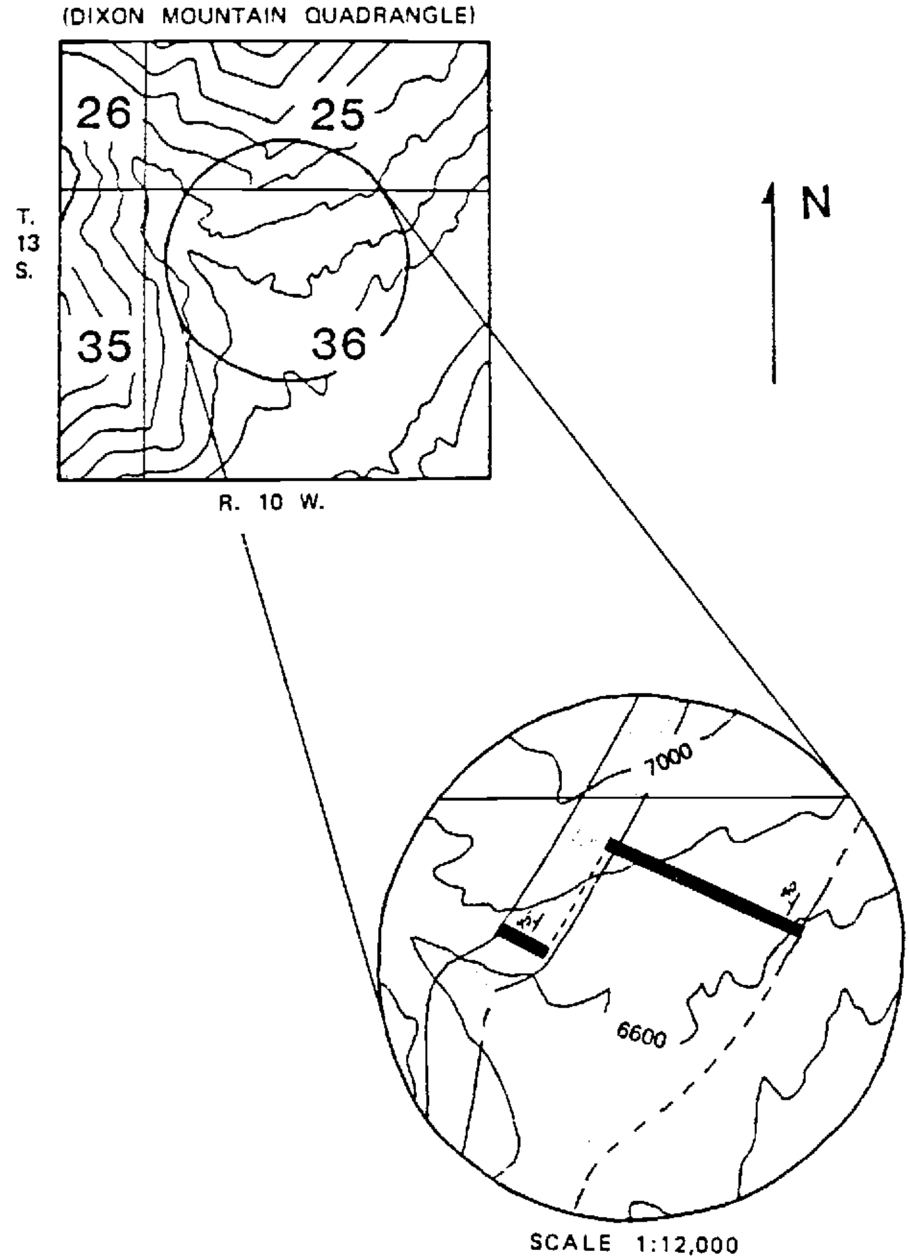

Figure 59. Bedrock geology and location of measured section transverse at Big Sheep Creek locality, Tendoy Mountains, Beaverhead County, Montana. See page 137 for explanation.

BIG SHEEP CREEK

Terminal Point: NE 1/4, NW 1/4, NW 1/4, sec. 36, T. 13 S., R. 10 W., Dixon Mountain 7.5 minute quadrangle, Beaverhead County, Montana. Just to the northeast of Hidden Pasture Creek on a prominent, northwesterly dipping ridge of Dixon Mountain; elevation about 6880 feet.

Thickness in feet

QUADRANT FORMATION (incomplete)

Lower Dolomite Interval (incomplete)

22) Quartz arenite, dolomite-cemented, series of ledge-formers, yellowish gray (5Y 8/1), localized hematite stained zones, fine-grained, friable, porous, medium -to thickly bedded with numerous dime-sized, concretions....................................57

TOTAL MEASURED PART OF QUADRANT FORMATION............57

Contact. - Quadrant/unnamed limestone: gradational.

LIMESTONE UNIT (unnamed)

21) Covered interval.................................11

20) Wackestone, subdued ledge-former, light gray (N7), medium-bedded with brachiopod, crinoid, and Cystoporid and Rhabdomesid bryozoan fragments, localized chert stringers (2 x 7")..............................10

19) Mudstone, poorly exposed slope-former, yellowish gray (5Y 8/1)..........................16

18) Wackestones, series of ledge-formers, light olive gray (5Y 6/1), medium-bedded with brachiopod, crinoid, and bryozoa fragments, localized grayish black (N2), 6" chert stringers. The upper 3' of the unit grades into a brachiopod packstone characterized by undulatory contacts caused by dense concentrations of disarticulated brachiopod shells aligned parallel to bedding.............................10

17) Covered interval.................................10

16) Wackestone, ledge-former, light olive gray (5Y 6/1), medium-bedded with brachiopod, crinoid, and Trepostome, Fenestillid, and Rhabdomesid bryozoan fragments, locally bioturbated. The unit also contains 4-6" chert stringers and locally is heavily fractured...8

15) Mudstones, poorly exposed slope-formers, medium light gray (N6), thinly bedded............26

14) Wackestone, ledge-former, light gray (N7), medium-bedded with brachiopod and crinoid fragments, locally grading into a brachiopod packsone. The unit also contains numerous grayish orange (10YR 7/4) chert pods in the upper 2' (2 x 4")......................7

13) Mudstones, poorly exposed slope-former, medium light gray (N6), thinly bedded............24

12) Covered interval..................................12

11) Wackestones, series of ledge-formers, medium light gray (N6), medium- to thickly bedded with brachiopod, crinoid, and bryozoa fragments, locally grading into a brachiopod packstone or mudstone. The unit also contains sporadically dispersed 2" x 6", grayish orange (10YR 7/4) chert nodules..............................14

10) Mudstones, poorly exposed slope-former, medium gray (N5), thinly-bedded..................39

9) Wackestones, series of ledge-formers, medium gray (N5), thin to medium-bedded with crinoid and brachiopod fragments, localized shale partings and chert pods (2 x 4")....................................37

TOTAL LIMESTONE UNIT...............................<u>224</u>

Contact. - unnamed limestone/Conover Ranch: poorly exposed, appears sharp.

CONOVER RANCH FORMATION

8) Covered interval, shales (?)....................468

7) Quartz arenite, calcite-cemented, ledge-former, yellowish gray (5Y 7/2), locally hematite stained, very fine-grained, medium-bedded with unidentifiable fossil fragments, bioturbated(?)........................5

6) Covered interval.................................14

5) Quartz arenite, calcite-cemented, ledge-former, moderate yellowish brown (10YR 5/4), heavily hematite stained. The unit is very fine-grained, thinly bedded with subtle cross-bed sets containing pelecypod and gastropod fossil fragments..................10

4) Covered interval.................................64

3) Quartz arenites/siltstones, calcite-cemented, series of ledge-formers, moderate yellowish brown (10YR 5/4), locally heavy hematite-stained zones. The unit contains pelecypod fragments within planar and trough cross-bed sets, also some surfaces display sinuous, symmetrical ripples..............................70

2) Covered interval..................................9

1) Quartz arenite, calcite-cemented, small cliff-former, color ranging from very pale orange (10YR 8/2) to hematite-stained, moderate brown (5YR 3/4) basal portion. The hematite staining occurs as numerous 3-4 mm dots on the surface of the unit. The unit is fine-grained, massive, and heavily fractured, many surfaces display slickensides.....................................14

TOTAL CONOVER RANCH FORMATION.....................654

Contact. - Conover Ranch/Lombard Limestone: sharp, locally erosional with scour-and-fill structures(?).

Initial Point: SE 1/4, NE 1/4, NW 1/4, sec. 36, T. 13 S., R. 10 W., Dixon Mountian 7.5 minute quadrangle, Beaverhead County, Montana. Within a gully located about 1/4 of a mile to the northwest of Big Sheep Creek Road; elevation about 6600 feet.