AN ABSTRACT OF THE THESIS OF

David J. Byrne for the degree of Master of Science in Geology presented on November 8, 1985.

Title: Stratigraphy and Depositional History of the Upper Mississippian Big Snowy Formation in the Snowcrest Range, southwestern Montana.

Abstract approved -Redacted for privacy.
Prof. Keith F. Oles

The Big Snowy Formation in the Snowcrest Range reflects middle Meramecian through late Chesterian deposition in an intermittently silled trough in southwestern Montana. The name Big Snowy Formation has recently been supplanted by the Kibbey Formation and Lombard Limestone, which compose the lower two-thirds of the Snowcrest Range Group (new). The Kibbey is poorly exposed throughout the Snowcrest Range, but can be subdivided into two informal units based on measurements in the Blacktail Mountains, just north of the study area. The lower unit consists predominantly of silty and sandy dolostones which represent deposition in an upper intertidal to lower supratidal environment. Calcite- and dolomite-cemented quartz arenites, deposited on a lower shoreface to lower intertidal environment, compose the upper unit. The Kibbey unconformably overlies the Mission Canyon Limestone and is conformably overlain by the Lombard Limestone.

Lombard carbonate sedimentation denotes rapid basin subsidence and consequent migration of the Kibbey shoreface to the

east in late Meramecian time. Four lithofacies are recognized in the Lombard, which are, in ascending order of predominant stratigraphic occurrence, (1) lime mudstone, (2) fossiliferous wackestone-packstone, (3) calcareous shale, and (4) dolomitic lime mudstone lithofacies. The first two lithofacies display an intertonguing relationship recording episodic differential subsidence in the trough. Rapid basinwide subsidence and consequent deposition in a stratified water column are reflected in the last two lithofacies.

Seven major Late Mississippian tectono-sedimentary events are suggested by regional relationships of the Lombard lithofacies in the study area and correlative units in east-central Idaho and central Montana. Times of uplift or cessation of subsidence on the outer cratonic platform seem to correlate to times of increased subsidence on the inner cratonic platform, and vice versa. Lombard sedimentation responded to the combined influences of episodic subsidence within the trough and to two periods of carbonate bank development on the outer cratonic platform. The lower part of the Lombard is dominated by the lime mudstone lithofacies, which was deposited in a slightly silled basin behind the Scott Peak carbonate bank complex.

Drowning of the bank in early Chesterian time corresponds with a major progradational event documented in the upper part of the Lombard. Upbuilding of the Surrett Canyon bank in late Chesterian time occurred concomitantly with rapid subsidence of the Snowcrest trough, creating a deep, silled, vertically stratified basin characterized by calcareous shale deposits. Subsequent shoaling of the trough is recorded in the dolomitic lime mudstone lithofacies, which disconformably underlies the overstepping Conover Ranch Formation in the study area.

Geochemical analyses of the lime mudstone and calcareous shale lithofacies of the Lombard indicate a moderate to good petroleum source rock potential.

STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE UPPER MISSISSIPPIAN BIG SNOWY FORMATION IN THE SNOWCREST RANGE, SOUTHWESTERN MONTANA

by

David Jerome Byrne

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Redacted for privacy

Dean of Graduate School

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INTRODUCTION

Location

The Snowcrest Range is located in southeastern Beaverhead and southwestern Madison Counties, approximately 33 miles southeast of Dillon, Montana. The range, which rises abruptly above the gentle, low-relief hills and valleys which surround it, describes a northeast to southwest arc (Fig. 1), and is overthrust and overturned to the southeast. The area under study encompasses approximately 440 square miles and incorporates nine U. S. Geological Survey 7.5 minute quadrangles, which, from southwest to northeast, are the Lima, Henry Gulch, Lima Dam, Whiskey Springs, Antone Peak, Swamp Creek, Stonehouse Mountain, Spur Mountain, and Home Park quadrangles. The Snowcrest region, as defined here, lies between 44°40' and 45°02' north latitude, and 111°58' and 112°30' west longitude (Fig. 1).

Purpose of Study

The principal goals of this study are: (1) to measure and construct several detailed stratigraphic sections through the Upper Mississippian Big Snowy Group rocks exposed along the length of the Snowcrest Range; (2) to subdivide the Big Snowy Formation into members or lithofacies; (3) to determine the Late Mississippian depositional environments in the Snowcrest Range area; (4) to correlate these rocks to regionally equivalent units; (5) to provide

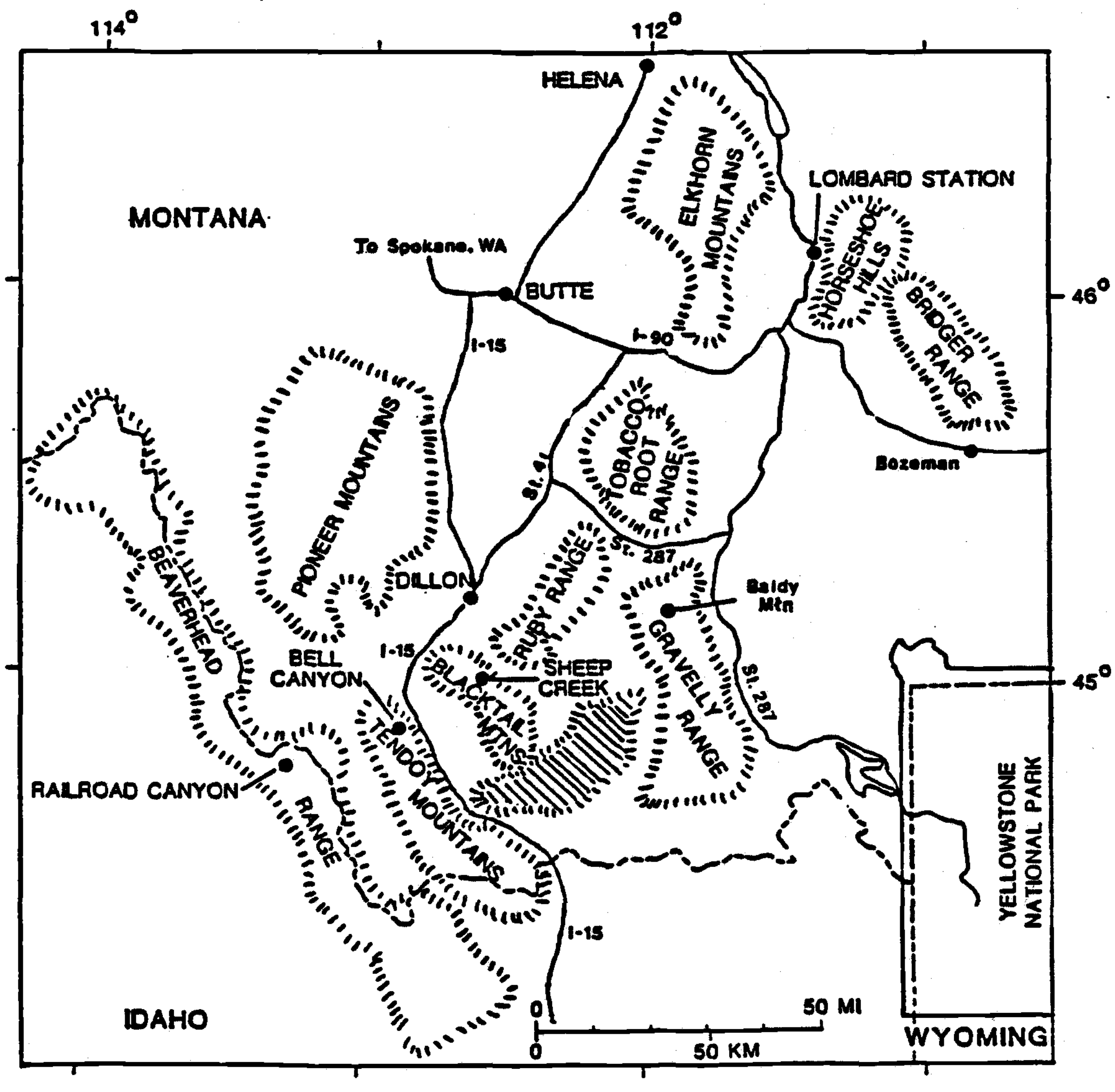


Figure 1. Location map of southwestern Montana and adjacent Idaho, showing mountains and specific locations mentioned in text. Snowcrest Range illustrated with cross-hatched pattern. Figure modified from Wardlaw and Pecora (1985).

evidence for deposition in an unstable, subsiding trough; and, (6) to analyze the hydrocarbon source-rock potential of the Upper Mississippian rocks in the Snowcrest Range area. Very little detailed work has been accomplished in the Snowcrest Range. To my knowledge, no one has undertaken a stratigraphic analysis of the Big Snowy Formation involving detailed petrographic, biostratigraphic, or geochemical analyses. This paucity of investigation probably can be attributed to the inaccessibility of the heart of the range where the upper Paleozoic rocks are best exposed. Previous reconnaissance work did reveal an exceptionally thick Carboniferous sequence here, meriting a detailed investigation of these rocks (Klepper, 1950; Gealy, 1953). The location of the Snowcrest Range, with respect to the inferred geometry of the Snowcrest trough, affords an unsurpassed opportunity to study Big Snowy deposition in an axial part of the Snowcrest trough.

This report concentrates on the late Meramec and Chester age Big Snowy Formation. A complementary report on the latest Chester and Pennsylvanian Amsden Formation and lower part of the Quadrant Formation is concurrently being prepared by Colin Key, also of Oregon State University.

Accessibility

Three gravel and dirt roads, which follow the major valleys, permit access into the Snowcrest Range area (Fig. 2). The southwestern end of the range can be reached along either the Centennial Divide or Blacktail Deer Creek roads. The Centennial Divide road continues north along the easternmost flank of the

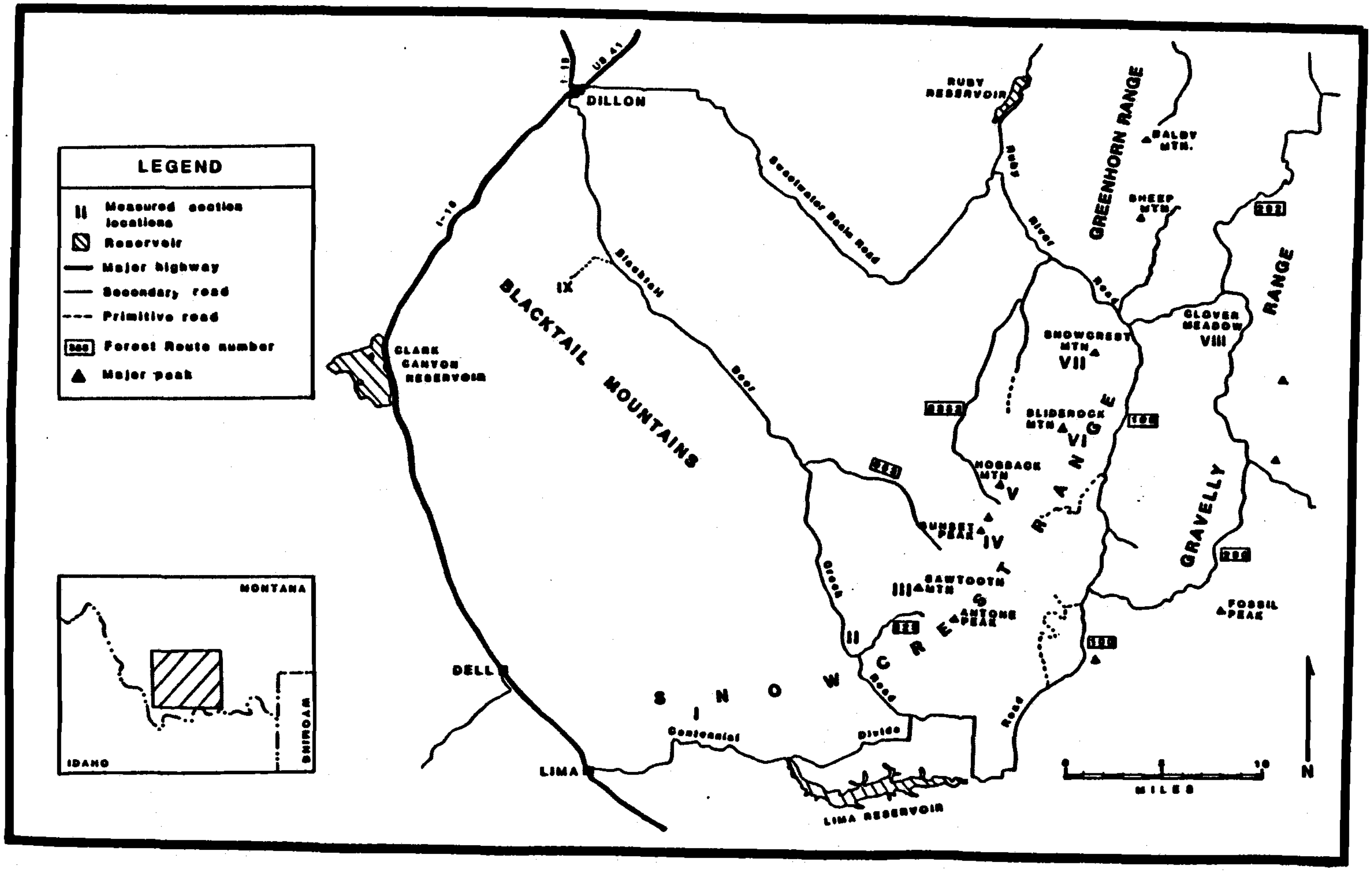


Figure 2. Map of Snowcrest Range area, showing major peaks, access routes, and measured section localities (numbers correspond with general locations of measured sections listed in Appendix A). Rivers and streams not shown.

Snowcrest Range and eventually joins with the Ruby River road north of Lone Butte. The northeastern end of the range is best approached from the town of Alder, Montana, via the Ruby River road. This road is generally well maintained throughout the summer months and can be travelled during and after inclement weather with few problems. Centennial Divide and Blacktail Deer Creek Roads can present difficult driving conditions, however, and are often impassable immediately following heavy rains. Access into the range is usually best during July, August, and early September.

Several secondary dirt roads provide access to the western part of the range, the most notable including the Antone Peak (Forest Route 325), East Fork Blacktail Deer Creek (Forest Route 963), Ledford Creek (Forest Route 8353), and Robb Creek roads. Most of the secondary roads are impassable to two-wheel drive vehicles during much of the summer because of mud from daily thundershowers, or from gully erosion which incises the roads. Access to the interior of the Snowcrest Range is restricted to foot, horseback, or helicopter.

Geomorphology And Climate

The Snowcrest Range is a succession of hogbacks which rise gradually in elevation from low, rolling hills at the southwestern end to narrow, precipitous ridges in the central and northern parts of the range (Fig. 3). Resistant Carboniferous and Permian rocks form the backbone of the range throughout the 40 mile length. The principal crest of the range attains a maximum elevation of

Figure 3. View of the Snowcrest Range, showing hogbacks which define the ridge line. Three highest peaks, from right to left, are Sunset and Olsen Peaks, and Hogback Mountain. View is to the north from Sawtooth Mountain.

10,605 feet at Hogback Mountain; to the north the major peaks maintain summit elevations in excess of 9,000 feet. The central part of the range, where a the maximum relief of approximately 4,900 feet is attained, is characterized by six peaks which exceed 10,000 feet in elevation.

A characteristic ridge-valley-ridge geomorphological expression is ubiquitous in the Snowcrest Range wherever the Mission Canyon Limestone, Big Snowy, Amsden, and Quadrant Formations are all present. The Quadrant typically caps the highest peaks and ridges in the range, except where the Permian Phosphoria Formation overlies the Quadrant on the normal-up limb of the overturned anticline. Each Quadrant-supported ridge is typically paralleled by a subordinate ridge of Mission Canyon limestones and dolomites. These two ridges are separated by the less resistant valley- and saddle-forming Big Snowy and Amsden Formation rocks (Figs. 3 and 4). At several locations where the Mission Canyon is missing because of thrust faulting, the Big Snowy rocks form a subordinate ridge or hill adjacent to the Quadrant ridges which is best displayed at Sawtooth and Hogback Mountains. The Amsden Formation is the least resistant of the four units in the range.

The linear continuity of the Snowcrest Range is broken by three drainage systems which dissect the ridge line and divide the range into four distinct sections. These four drainage systems, from southwest to northeast, are Blacktail Deer, Robb, and Ledford Creeks (Fig. 2). The natural structural extension of the range to the north-northeast is the Greenhorn Range. It is separated from the Snowcrest Range by the antecedent Ruby River which flows 15

Figure 4. View of typical geomorphologic expression of upper Paleozoic units, showing characteristic valley between two ridges or hills composed of Madison Group (Mmc) carbonates and Quadrant Formation (ⱣPq) sandstones. Photo in southwesternmost part of the range, looking north (Mbs=Big Snowy, MⱣPa=Amsden).

miles northward from its origin on the southeastern flank of the central Snowcrest Range before abruptly swinging northwest through the watergap between the two ranges.

Gently sloping erosional benches, cut into overturned and normal-up Mesozoic and Tertiary units, skirt the Snowcrest Range on both the northwest and southeast sides. The rugged nature of the range was enhanced in Wisconsin time when glaciers carved cirques and small valleys in the higher parts of the range. Failure of the overturned, northwestward-dipping Big Snowy Formation has resulted in the development of large, recent landslides near Spur and Snowcrest Mountains (Fig. 5).

The climate of southwestern Montana is semi-arid as a result of its interior position immediately east of the continental divide. Annual precipitation averages 15 inches, and is greatest from April through July. Summer temperatures range from lows in the upper thirties at night, to highs near 100°F during the day. During the summer the Snowcrest Range is characterized by afternoon thunderstorms which sweep over the range on a near-daily basis.

Investigative Methods

Field work was accomplished over a ten week period, from June 27 to September 1, 1985. Seven stratigraphic sections were measured at nearly equal spacings along the length of the Snowcrest Range, as well as one section each in the Blacktail and Gravelly Ranges (Fig. 2). A total of 10,920 feet of section were measured and described.

Figure 5. Recent landslide deposits involving failure within the Big Snowy Formation, on western flank of northern Snowcrest Range. View is to southwest from Snowcrest Mountain area. Sliderock and Spur Mountains in distance.

Adequate exposures of the Big Snowy Formation, permitting detailed stratigraphic analysis, are largely limited to the high peaks in the Snowcrest Range, and the northeastern flank of the Blacktail Range. The partial Big Snowy Formation section measured in the northern part of the Gravelly Range has not been reported before, and this is the first reported occurrence of Big Snowy rocks east of the Greenhorn Fault, which defines the southeastern edge of the Snowcrest and Greenhorn Ranges. Previous workers had assigned these rocks to the Mission Canyon Limestone (Hadley et al., 1980).

Individual field stations were recorded daily in a notebook and pertinent structural data and formation contacts were transferred onto U. S. Geological Survey 7.5 minute topographic maps having a scale of 1:24,000. Stratigraphic thicknesses were measured using a Jacob's staff and Abney level, or with a metal tape with subsequent adjustments for bedding attitudes. Individual bed thicknesses were measured in the field with a metal tape; the terminology used for stratification and splitting properties is based on standards established by McKee and Weir (1953). Bedding attitudes were measured with a Brunton compass.

Sandstones were classified according to Williams, Turner, and Gilbert (1954). A reference sand grain gauge was utilized in the field for determining sand grain size (after Wentworth, 1922) and roundness (after Powers, 1953). Carbonate rocks were classified in the field according to Dunham (1962), and additionally classified according to Folk's (1962) terminology in the laboratory. The degree of crystallinity of the carbonate rocks was recorded relative to the Wentworth scale for clastic rocks (Wentworth, 1922); fine, medium, and coarsely crystalline carbonates are directly analagous to fine, medium, and coarse sand-size fractions. The Geological Society of America Rock-Color Chart (Goddard et al., 1970) was used to determine rock colors on both fresh and weathered surfaces. Dolomite was contrasted with calcite in the field by comparing the rate of effervescense upon application of hydrochloric acid to a fresh rock surface. The dolomite typically yielded a slower and less energetic reaction.

For lithological and/or paleontological analysis, 350 rock samples were collected in the field. Each sample taken for lithological study was removed directly from outcrop; float samples were not utilized. However, a small number of fossil collections were made from float, but only where the beds which were the source were obvious. An additional 22 samples were taken for geochemical analysis, to determine hydrocarbon source rock potential. Only the freshest surface samples obtainable were collected from promising intervals; generally, samples could not be broken out beyond one to two feet deep into the outcrop. These samples were immediately wrapped, unmarked, in several layers of aluminum foil and labeled externally. Direct handling of each sample was kept to a minimum.

All of the samples collected for lithological analysis were cut and polished for inspection under a binocular dissecting microscope; 180 samples were then selected for thin section analysis. The presence of dolomite was determined by petrographic analysis (using Alizarin Red stain), and X-ray diffraction techniques.

A total of 72 coral and bryozoan samples, and 46 brachiopod samples, were identified and zoned by Dr. W. J. Sando and Dr. J. T. Dutro, respectively, both of the U. S. Geological Survey in Washington, D. C. Additional analysis of paleontological material was facilitated by Dr. J. G. Johnson, Bob Blodgett, and Ning Zhang, all of Oregon State University.

Rocks collected for geochemical analysis were sent to Tenneco Laboratories in Houston, Texas. Geochemical analyses to determine hydrocarbon source rock potential included total organic carbon, kerogen content, soluble organic matter, spore color indexing, and vitrinite reflectance. Of these samples, Rock-Eval Pyrolysis and gas chromatography tests were completed on eight samples which displayed indices supporting a fair to good source rock potential.

Geological Setting

The Montana-Wyoming-Idaho tri-state region occupied a position on the westernmost edge of the stable North American craton throughout Mississippian time. This part of the craton, known as the Cordilleran platform, was bordered on the northeast by the Canadian shield, and on the east by the Transcontinental arch, a linear, northeast-trending positive element which extended from southern Manitoba to northern Mexico. To the west, the platform was bordered by the Cordilleran geosynclinal belt. Within this belt, three tectonic elements can be discerned: the western Cordilleran eugeosyncline, the eastern Cordilleran miogeosyncline, and the intervening positive Antler orogenic belt (Fig. 6; Sando, Gordon, and Dutro, 1975).

Most of Montana, Wyoming, and western North and South

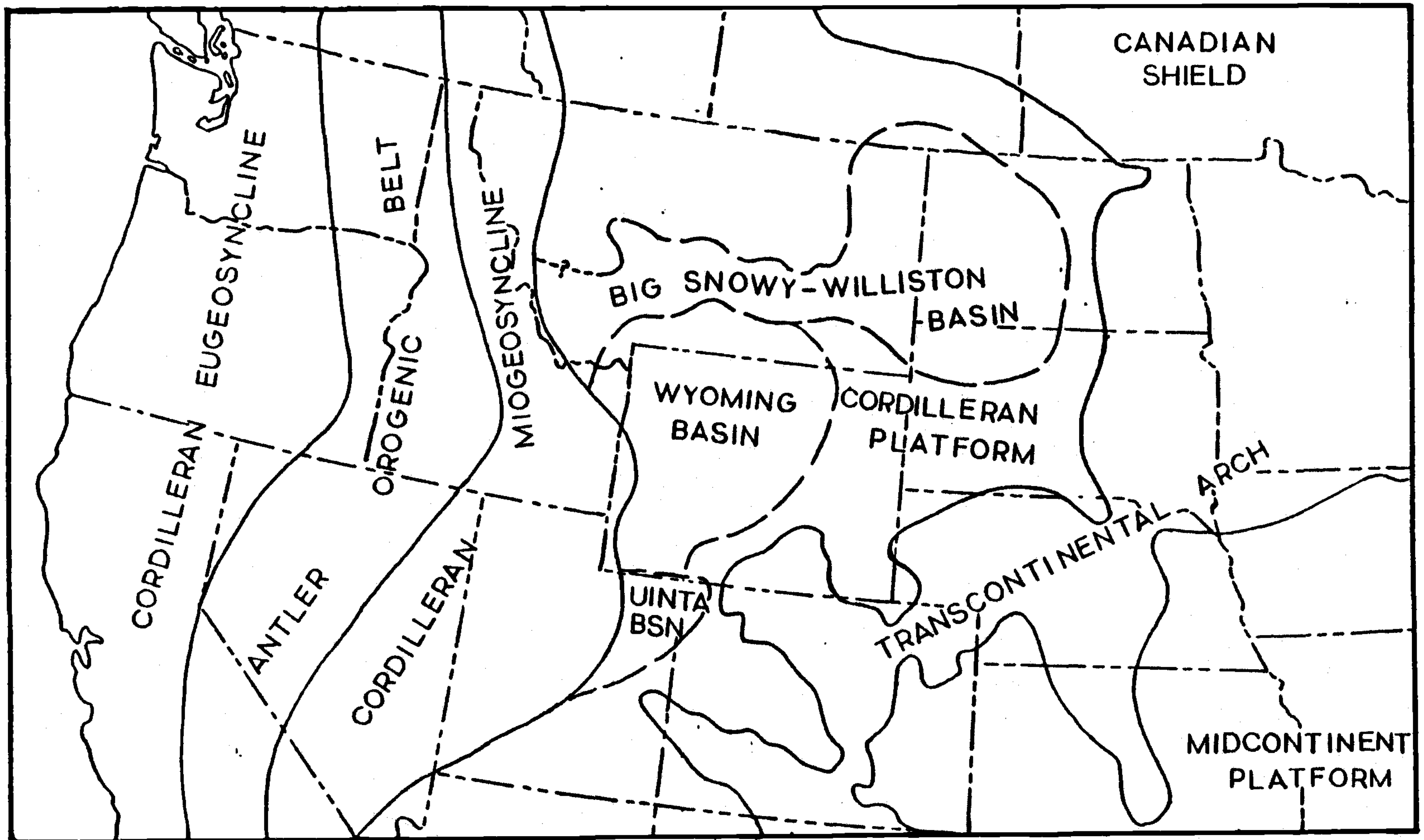


Figure 6. Mississippian paleotectonic elements in the western United States (compiled from Bissler (1976), Sando (1976), Smith and Gilmour (1979), and Maughan (1984).

Dakota were occupied by a broad cratonic platform during the Paleozoic Era. Orogenic activity, related to plate collision from latest Middle Devonian to early Mississippian time, created instabilities in the previously more stable platform, causing differential movement within both the platform and geosynclinal belt (Gutschick and Sandberg, 1983; Sando, 1976). Deposition of Mississippian strata in the northern Rocky Mountain region thus reflects the direct and indirect influence of regional orogenic activity which generated variability within the paleotectonic elements of western North America.

Three major incipient or rejuvenated areas of intracratonic instability, transverse to the craton margin, exerted significant control on Carboniferous sedimentation (Fig. 6). The northernmost of these, the Big Snowy trough in central Montana, developed in late Kinderhook time just north of the position of the early Paleozoic central Montana trough (Peterson, 1981). This east-west-trending structural sag permitted a direct connection of the Williston basin sea, in eastern Montana, western North and South Dakota, and southern Saskatchewan, with the Cordilleran sea to the west.

Mississippian isopach maps indicate that considerable downwarping occurred in the trough in Osage and earliest Meramec time. Rejuvenation of downwarping, subsequent to brief epeiric uplift associated with anorogenesis, is indicated by a thick, areally restricted late Meramec- Chester section in the Big Snowy trough (Craig, 1972).

Tectonic activity during this latter time promoted the growth of several local uplifts and new source terranes peripheral to the subsiding basins, initiating an influx of terrigenous material into the platform region unknown in Early Mississippian time (Sando, 1976).

The western extension of the Big Snowy trough, in southwestern Montana, is called the Snowcrest trough (Fig. 7; Maughan and Roberts, 1967). Recently, the names Ruby and Blacktail-Snowcrest trough have been cited as well (Peterson, 1981; Pecora, 1981). The Big Snowy and Snowcrest troughs were separated by a northwest-trending positive element, the Lombard arch, which was located immediately north of the Bridger Range in southwestern Montana (Fig. 7). Big Snowy and Amsden strata thinned over this structural high and a major facies change within the upper Big Snowy has been noted across the arch (Blake, 1959; Harris, 1972).

The mechanisms of the instability responsible for the location of the Big Snowy and Snowcrest troughs across Montana are uncertain. These unstable troughs are coincident with a hypothesized Precambrian aulacogen which projected into the craton from a major salient of the continental margin in east-central Idaho (Maughan, 1984). The zero thickness line of the Big Snowy Group sediments, which is primarily fault controlled, corresponds closely with the margins of both the Big Snowy and the Snowcrest troughs. Additionally, the overlying Amsden Group is less restricted areally than the underlying Big Snowy Group, suggesting that syndepositional and/or post-depositional (pre-Amsden) faults may have played a major role in controlling the geometry of the

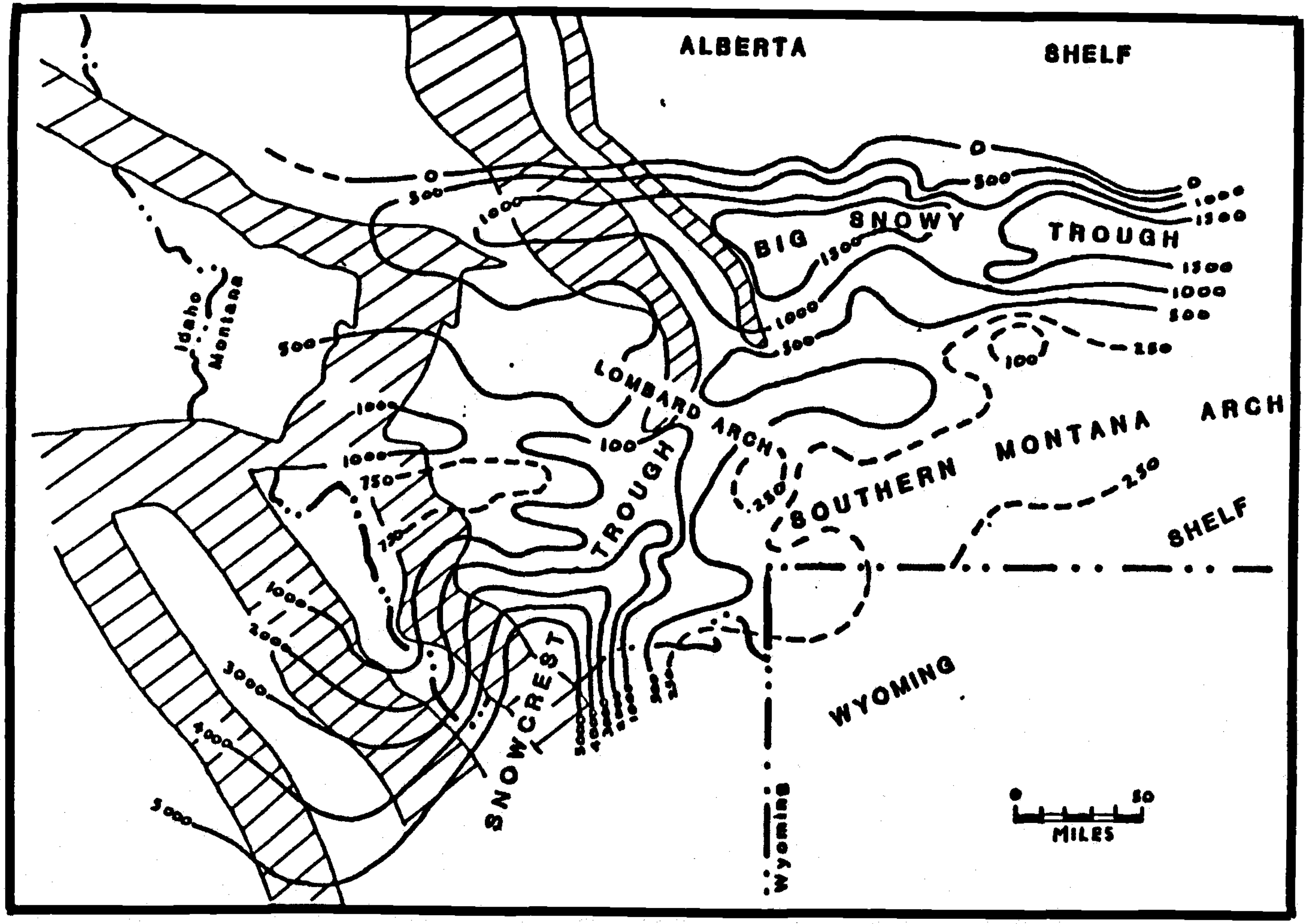


Figure 7. Isopach map of Late Mississippian rocks of southwestern Montana. Palinspastic restoration to account for Mesozoic and Cenozoic thrusting shown by cross-hatched pattern (modified from Peterson, 1981).

trough during Big Snowy deposition (Mallory, 1972).

Subsidence of the Big Snowy-Williston, Wyoming, and Uinta basins isolated intervening shelf areas, which also varied in stability through Carboniferous time, locally becoming positive elements which influenced sedimentation patterns. The northern margin of the Big Snowy-Snowcrest trough in Mississippian time was bordered by the relatively neutral Alberta shelf (Fig. 7). The extent of Big Snowy deposition north of the presently recognized trough margin is unknown because of the pre-Jurassic uplift and erosion of the southern part of the Alberta shelf known as the Milk River uplift (Smith and Gilmour, 1979).

South of the trough, the Wyoming shelf (Beartooth platform of Peterson, 1981) seems to have varied in stability from middle Meramec to late Chester time. Outliers of Kibbey(?) Formation sandstones suggest an intermediate degree of tectonic stability in early Chester time (Sando et al., 1975). By middle Chester time, however, a positive peninsular element, the southern Montana arch, had developed along the southern Montana state line area, separating the Wyoming and Big Snowy basins until latest Chester time (Sando, 1976).

Snowcrest Range setting

Southwestern Montana is characterized by two distinctly different structural and stratigraphic fabrics which reflect the transition across the Mississippian hinge line, from the cratonic platform setting to the the miogeosynclinal setting. This hinge line, named the Wasatch line by Kay (1951), extends from northwestern Mexico to southeastern British Columbia (Fig. 6; Stokes, 1976). The miogeosynclinal area is typified by complex, northwest-trending, Sevier-type thrust faults and associated asymmetric to recumbent folds (Perry and Sando, 1982). An extremely thick sequence of upper Paleozoic rocks is found here, which has been tectonically thickened by structural telescoping.

East of this complex terrane, in the former cratonic shelf area, major thrusts occur along the flanks of broad anticlinoria involving the Precambrian crystalline basement. These broad uplifts radiate outward from a common origin in the Tobacco Root Mountains region. In clockwise fashion, from east to west, these major arches are the Madison-Gallatin, Madison-Gravelly, and BlacktailSnowcrest uplifts, separated by the Madison and Upper Ruby synclinoria, respectively (Fig. 8; Huh, 1967). Upper Paleozoic units are substantially thinner here, except in the Snowcrest trough area, where an anomalously thick Carboniferous sequence is present (Peterson, 1981).

The Snowcrest Range is a southeast-verging asymmetric to overturned anticline associated with basement-involved thrusting on the southeastern flank of the Laramide Blacktail-Snowcrest uplift. Fault-related folding juxtposes hanging wall anticlines against footwall synclines in the central and northern parts of the range.

Uplift of the Snowcrest Range has been facilitated by two to five miles of southeastward transport along the southwest-northeast-trending, Late Cretaceous to early Eocene Snowcrest and Greenhorn faults, collectively referred to as the Snowcrest-Greenhorn thrust system (Scheedlo, 1984). The

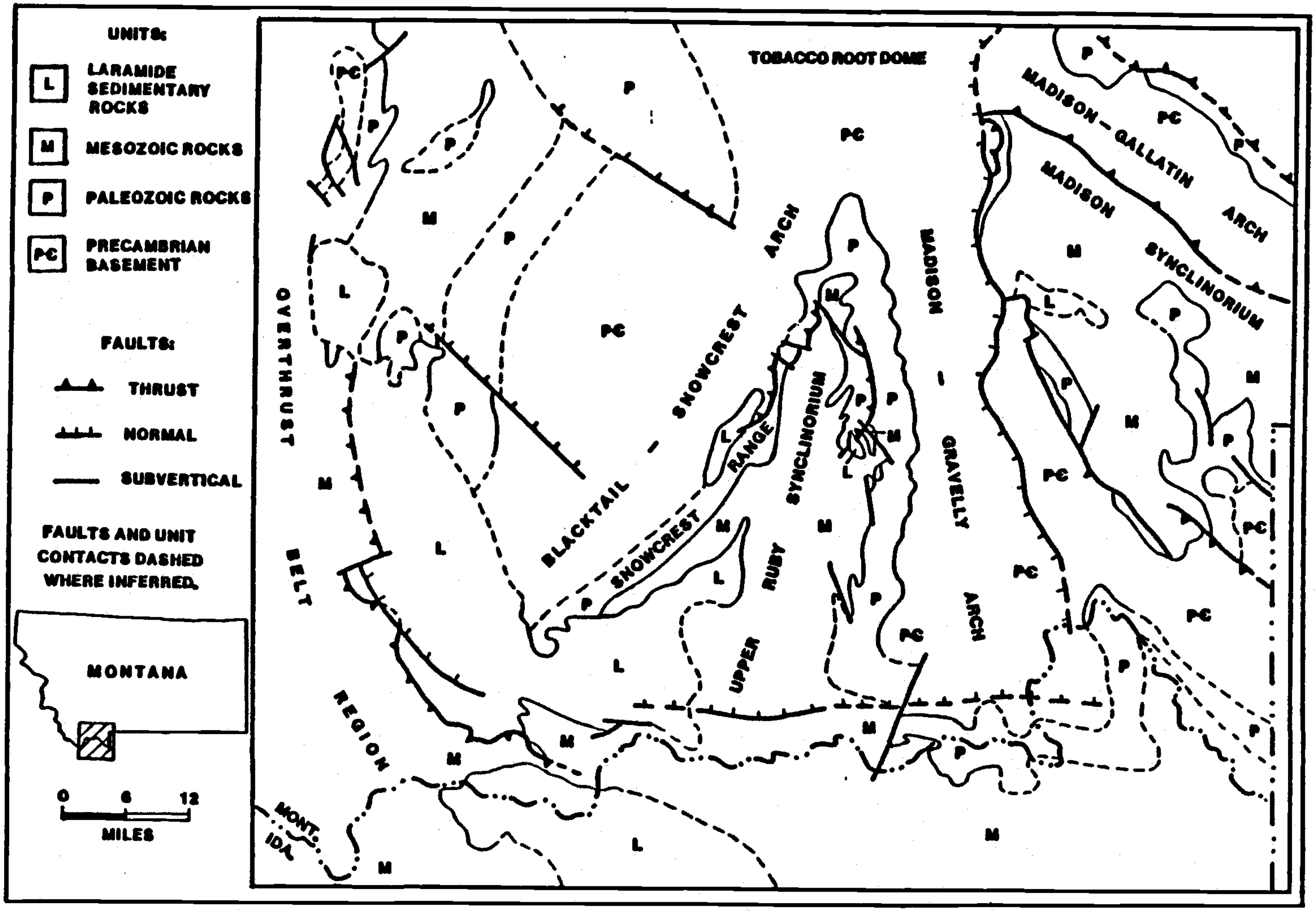


Figure 8. Geologic map of southwestern Montana. Post-Laramide sedimentary and volcanic rocks have been removed (From Scholten, 1967).

northwestern flank of the range is outlined by listric range-front normal faults which parallel the thrust faults and are down-dropped to the northwest. These normal faults, in addition to the northwest-trending tear faults which dissect the range, have largely defined the Ruby basin, a half-graben lying northwest of the Snowcrest Range (Scheedlo, 1984).

The Snowcrest-Greenhorn lineament parallels an earlier zone of basement weakness along the northwestern margin of the Carboniferous Beartooth platform, and is believed to have played a major role in Late Mississippian and Pennsylvanian sedimentation in this area (Perry et al., 1983). Pre-Amsden uplift on the east side of the Greenhorn fault removed the entire sequence of Big Snowy rocks, yet a 600 foot thick section is present on the west side of the fault (Hadley et al., 1980).

Uplift in the Gravelly Range (Fig. 1) took place in late Paleocene and Eocene time in response to regional east-west compression and consequent eastward displacement along detachment thrusts at depth. Development of this north-trending Gravelly Range fault zone was coincident with the culmination of thrusting and folding along the Snowcrest-Greenhorn thrust system (Scheedlo, 1984).

The Blacktail Range (Fig. 1), immediately north-northwest of the Snowcrest Range, is made up of allochthonous Paleozoic through Cretaceous strata thrust from the west (Pecora, 1981). Big Snowy exposures here are good, but tectonic thickening and complex folding in these rocks, typical of the Overthrust belt, is prevalent throughout the range.

PREVIOUS INVESTIGATIONS

Introduction

Three major depositional packages of inner cratonic platform origin are recognized in the Mississippian and Lower Pennsylvanian rock record in Montana. These are, in ascending order, the Madison, Big Snowy, and Amsden Groups.
Each group represents a major diachronic cycle separated by a hiatus of variable duration, which is generally shortest near the miogeosynclinal axis (Fig. 9; Sando et al., 1975). Paleotectonic conditions in Montana were similar throughout Mississippian and Pennsylvanian time, although the progressive increase in clastics delivered to the Big Snowy and Snowcrest troughs is reflected in the unique stratigraphy of each aforementioned group.

The historical development of Big Snowy nomenclature, spanning almost one century, has involved several changes of the upper and lower boundaries, age assignment, areal distribution, and correlation with time-equivalent units in adjacent depositional basins. The reader is referred to plate 1 to facilitate a better understanding of the development of the Big Snowy nomenclature, which will be discussed first.

Historical development of nomenclature

The Quadrant Quartzite and Formation

Carboniferous age rocks in southern Montana were first mapped and described by Iddings and Weed (1899) during a ten year long study in the Gallatin Range (1883 - 1893), where they named

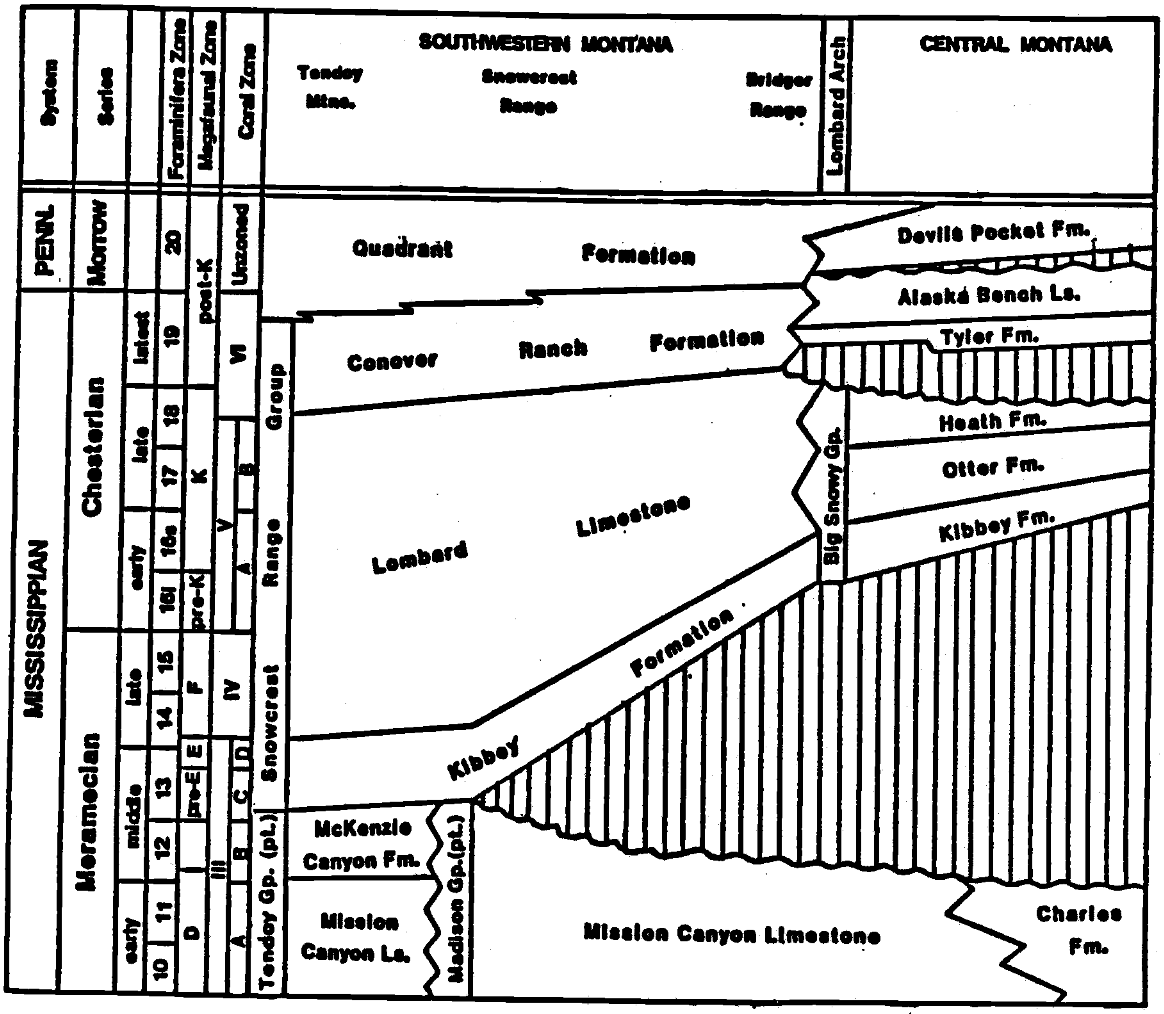


Figure 9. Nomenclature, faunal zonation, and temporal relationships of Upper Mississippian and Lower Pennsylvanian units in southwestern and west-central Montana. Compiled from Sando and others (1975), Davis (1983), Guthrie (1984), Sando and others (1985), and Wardlaw and Pecora (1985).

the Quadrant Quartzite from exposures on the southwest corner of Quadrant Mountain (Weed, 1896). In this area the name Quadrant was used for the strata between the underlying Lower Carboniferous Madison Limestone and the overlying Permo-Triassic Teton Formation (subsequently renamed the Phosphoria Formation). Following a field conference with Iddings and Weed, prior to publication of their type section in northwestern Yellowstone Park (Iddings and Weed, 1899), Peale (1893) applied the name Quadrant Formation to rocks in the Three Forks area which he believed to be stratigraphic equivalents to the quartzites on Quadrant Mountain.

During field work in the Little Belt Mountains of central Montana, Weed (1896, 1900) subdivided the Quadrant Formation into two new formations and raised the Quadrant to group status. The basal formation, the Kibbey Sandstone, was named for reddish and yellowish, argillaceous, gypsiferous sandstones resting unconformably on the Madison Limestone. No type locality was established, but moderate to good exposures are known near Kibbey School on Little Otter Creek, and along Belt Creek, near Riceville, Montana (Weed, 1899, 1900; Easton, 1962).

Weed designated the green and gray shales intercalated with thin limestones, which conformably overlie the Kibbey, as the Otter Formation. Both the Kibbey and Otter were assigned a Mississippian(?) age. On the north side of the Judith River, near Utica, he identified an overlying succession of limestones and sandstones below the unconformably overlying Jurassic Ellis Group; he left this sequence undifferentiated, but included it in the

Quadrant Group (Weed, 1900).

In a later study to determine the source beds and reservoirs of oil accumulation in central Montana, Freeman (1922) returned the Quadrant to formational status and proposed the addition of two new members above the Kibbey Sandstone and Otter Shale. Based on outcrops in the Big Snowy Mountains, east of the Little Belt Mountains, he introduced the Tyler Sandstone, white and red sandstones interbedded with varicolored shales, and the overlying Alaska Bench Limestone, a gray, fossiliferous limestone unit. A 100 foot thick gray shale, which he left unnamed, separates the two members.

Paleontologists of this time were uncertain of the exact age of the Quadrant Formation, advocating both a Mississippian and/or Pennsylvanian age for these rocks. Because of the similarity of fossils in the lower part of the Quadrant Formation to known Mississippian forms, and a fauna in the upper part resembling that of Permian rocks in Texas and Oklahoma, a Permo-Carboniferous age was suggested for the formation (Freeman, 1922). Hammer and Lloyd (1926) shortly thereafter published a detailed study of the Paleozoic formations of central Montana in which they concluded that the upper part of the Quadrant Formation is Pennsylvanian, based on the lithologic similarity to the Pennsylvanian Tensleep Formation in Wyoming.

Reeves (1931) argued, however, that the Quadrant Formation in central Montana is entirely Mississippian based on faunal evidence which confirmed, with one exception, a Chester age for the uppermost limestone beds. Consequently, he included all of the rocks resting between the Madison Limestone and the Ellis Group, in the Big Snowy Mountains, in the Quadrant Formation. He did not, however, subdivide the Quadrant into the formal units recommended by Weed (1900) and Freeman (1922). The one exception, a fauna identified as belonging to an "obscure phase of the Chester or of the Pottsville", led Reeves to point out the possible equivalency of the uppermost Quadrant Formation in central Montana with the lower part of the Amsden Formation in northern Wyoming.

Introduction of the Big Snowy Group

Scott (1935) commented on the historically loose application of the Quadrant Formation to rocks ranging in age from Middle Mississippian to Permian, concluding that the

> "...lack of knowledge of the meaning of the term 'Quadrant' has led many geologists to consider the rocks of this formation as extremely variable in nature; yet, certain thin zones of limestone and shales are persistent under many hundred square miles in central Montana."

At the type section in Yellowstone Park, the Quadrant Quartzite was originally described as a sequence of "white, yellowish, and occasionally pink beds of quartzite with intercalated beds of drab saccharoidal limestone", underlain by a 100 foot thick talus slope (Weed, 1896). Scott (1935) traced the Quadrant Quartzite northward from its type locality and observed that the formation thins to a zero edge five miles north of Lombard, Montana, and that, in general, the calcareous zones become more significant west and northwest of the type locality. He also established that the Amsden of northern Wyoming, consisting of a lower red magnesian shale or sandstone member and upper limestone member, extends northward into central Montana, thus concurring with Reeves' (1931) earlier hypothesis. Reeves had previously correlated the limestone beds in the uppermost Quadrant Formation of central Montana to the lower part of the Quadrant Quartzite in northern Wyoming.

To resolve this Quadrant Quartzite versus Quadrant Formation conflict, Scott (1935) analyzed the regional stratigraphic relationships of the units lying immediately above and below the Amsden Formation to establish the true connection between the Quadrant of central Montana and that of northern Wyoming. Through a series of southeast-tonorthwest cross sections he was able to show two very different lithological sequences, separated in time and space by the laterally continous, though lithologically variable, Amsden Formation (Fig. 10).

Based on recognition of a sandstone-limestone-shale series lying beneath the Amsden Formation in the Big Snowy Mountains, a series which was absent in northern Wyoming, Scott (1935) abandoned the term Quadrant in central Montana. He replaced it with the Big Snowy Group (new) and the overlying Amsden Formation. In the Big Snowy Group he included the Kibbey and Otter Formations of Weed (1900), and introduced a new, third unit, which he named the Heath Formation (Scott, 1935). The Heath, named for excellent exposures along the northern flank of the Big Snowies, is made up chiefly of black, petroliferous and fossiliferous shales with three thick sandstone units which occur in the upper half of the formation. Freeman (1922) had previously

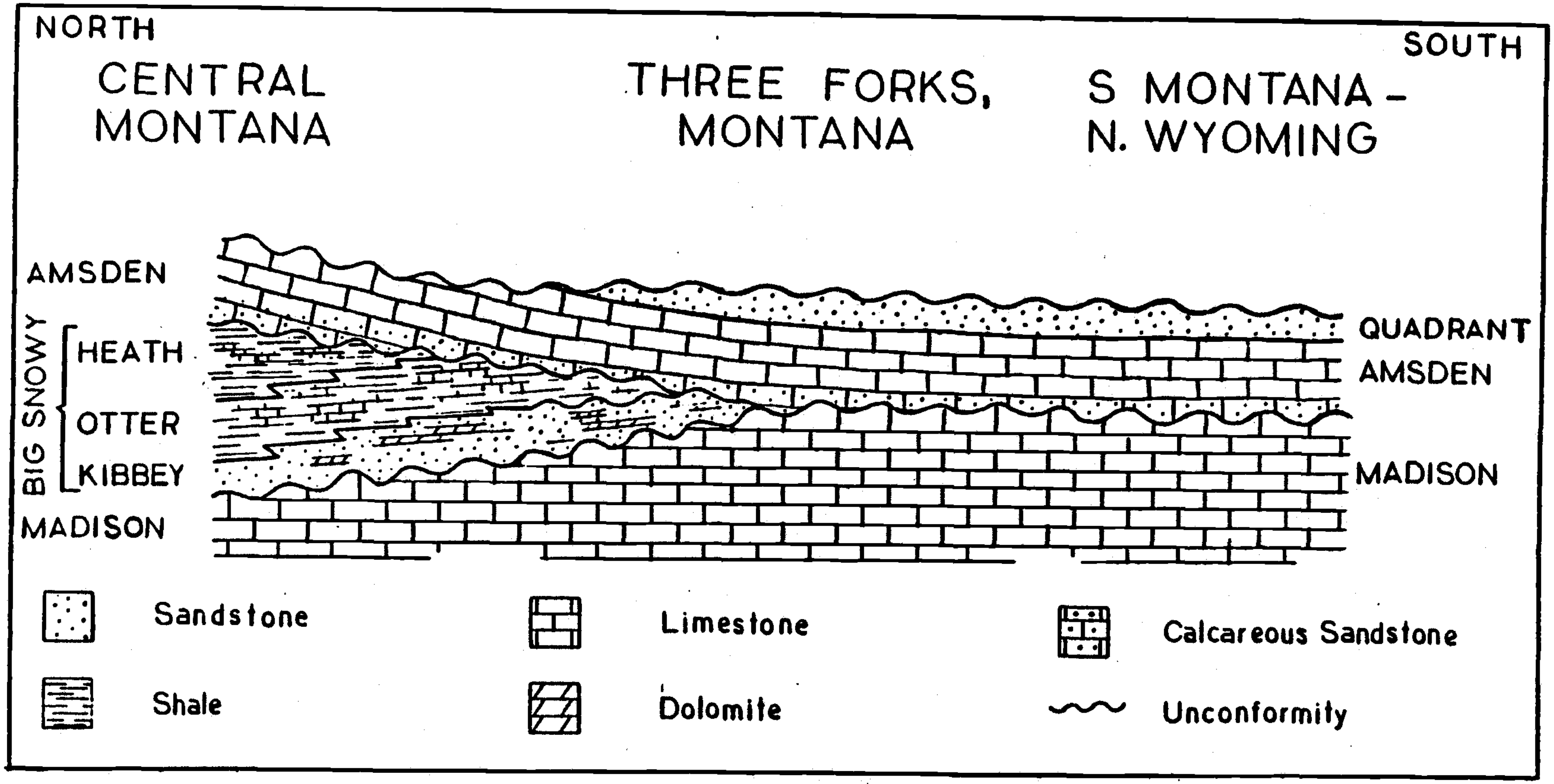


Figure 10. Diagrammatic north-south cross section showing spatial relationships of Carboniferous age rocks in Montana, as interpreted by Scott (1935).

classified these sandstones, and interbedded shales and thin limestones, under the name Tyler, and had placed the underlying shales in the Otter Formation. Scott (1935) disagreed with this division, and lowered the top of the Otter to a widespread limestone bed rich in productid brachiopods. This corresponds well with a relatively abrupt color change in the shales from vivid green to dark gray. Thus the Tyler and upper part of the Otter were supplanted by the Heath Formation.

All three formations in the Big Snowy Group were assigned a Chester age based on faunal evidence and stratigraphic position, the Heath being considered as "no older than Warsaw and no younger than upper Chester" (Scott, 1935). The Amsden Formation was presumed to be conformable with the underlying Heath Formation and, believing that the Amsden fauna more closely resembles the Chester fauna of the Heath than any Pennsylvanian fauna, the Amsden was designated as late Chester (Scott, 1935).

Following establishment of the tripartite Big Snowy Group, the main arguments involving Big Snowy nomenclature have focused on: (1) attempts to expand the group to include additional units, (2) correlation of the Big Snowy Group with time and stratigraphically equivalent units to the west, (3) the recognition of disconformities and erosional unconformities within and between the Mississippian and Pennsylvanian age strata, and (4) revisions of the stratigraphic position of the Mississippian-Pennsylvanian boundary which involve the top of the Big Snowy Group.

The Charles Formation conflict

In a well drilled in 1941 on the Cedar Creek anticline in southeastern Montana, a series of interbedded limestones, dolomites, anhydrites, and subordinate shales were encountered between the Madison Group and Kibbey Formation. This unit was subsequently called the Charles Formation and added to the base of the Big Snowy Formation, immediately below the Kibbey Formation (Seager, 1942). The Charles was offered as a possible depositional bridge, spanning the time between deposition of the upper part of the Madison and the lowermost Kibbey. The widespread development of porosity in the upper part of the Madison was considered indicative of a time break and resulted in inclusion of the Charles in the Big Snowy Group (Seager, 1942).

As the areal extent and lithological character of the Charles became more clearly understood, several workers countered the previously held notion that it represented initial Big Snowy deposition. Perry (fide Hadley, 1950), for instance, considered the Charles as a drying up phase at the end of Madison deposition. Brecciated fragmental limestones at the top of the Madison Group, and surface exposures of dense to saccharoidal dolomites (often colored pink to red),containing brecciated zones were subsequently correlated with the subsurface evaporitic Charles (Hadley, 1950; Sloss, 1952).

Analysis of the Madison Group and the Brazer Limestone to the west resulted in the recognition of the depositional contemporaneity of the upper parts of these units with the Charles of central and eastern Montana (Hadley, 1950; Sloss and Moritz, 1950), meriting inclusion of the Charles as the uppermost formation in the Madison Group. Additionally, the Kibbey rests with marked unconformity on the eroded and channelled surface of the Charles or the Mission Canyon near the margins of the Williston basin, establishing that a brief period of uplift and/or hiatus preceded deposition of the Kibbey Formation (Sloss, 1952).

The Mississippian-Pennsylvanian boundary problem

Accurate positioning of the Mississippian-Pennsylvanian boundary on paleontological grounds has been a problem ever since Weed (1900) first assigned a Lower Carboniferous age to the Quadrant Formation on uncertain fossil age determinations. Subsequent to the establishment of the Big Snowy Group and Amsden Formation as Mississippian, Scott (1945a, b) presented the first concrete evidence of a Pennsylvanian age for the upper part of the Amsden Formation, following discovery of a primitive fusilinid, the genus Millerella (this genus is now known to span latest Mississippian through Pennsylvanian time). Willis (1959) then lowered the boundary to a stratigraphic position coincident with the Heath-Tyler contact (the name Tyler was used earlier by Mundt (1956) to supplant the Lower Amsden Formation). Lowering the boundary to the top of the Heath was justified by the reported presence of an unconformity or scour zone at the base of the Tyler, and by the identification of a fauna in the Tyler of known Pennsylvanian affinity elsewhere (Willis, 1959).

In the same year, Gardner (1959) refuted the regional unconformity at the top of the Heath Formation, and expanded the

Big Snowy Group to include the overlying Cameron Creek, Alaska Bench, and Devils Pocket Formations, the first and last of these replacing the Tyler and Amsden/Tensleep of Mundt (1959), respectively. Gardner (1959) concluded that Mundt's (1959) erosional unconformity is actually a conformable Heath-Cameron Creek transition containing isolated channel deposits, and that the revised Big Snowy Group represents one essentially uninterrupted cycle of deposition.

Easton (1962) subsequently maintained the Big Snowy terminology of Gardner (1959), but noted a transitional Mississippian-Pennsylvanian character in the faunas of the Tyler Formation and Alaska Bench Member of the Amsden Formation. He also reestablished the regional unconformity on top of the Heath.

In a later report, Maughan and Roberts (1967) advocated an exclusively Mississippian age for the Big Snowy Group of Scott (1935), and a Pennsylvanian age for the overlying Amsden Group, as Willis (1959) had proposed earlier. Unlike Gardner (1959), Maughan and Roberts (1967) favored two cycles of deposition interrupted by a widespread erosional unconformity to explain the lithostratigraphic relationships of the Big Snowy and Amsden Group rocks. The Heath-Tyler unconformity is not well exposed in most areas, although substantial evidence is afforded in exposures in the Little Belt and Little Snowy Mountains in central Montana and in the subsurface of eastern Montana (Maughan and Roberts, 1967).

Maughan and Roberts (1967) established the time equivalence of the Big Snowy-Amsden Group lithostratigraphic boundary and the Mississippian-Pennsylvanian system boundary on two points of evidence. First, they commented,

> "It is believed that this unconformity was formed nearly contemporaneously with that unconformity which, by definition..., separates these two systems in the Mississippi Valley. The paleontologic evidence in Montana seems to confirm this accepted position."

Second, re-evaluation of Easton's (1962) fossil collection in consideration of this hypothesis indicated a Pennsylvanian age for those rocks which Easton had determined to be transitional, either Mississippian or Pennsylvanian in age, or both. To the time-equivalent rocks in southwestern Montana they assigned the name Big Snowy Formation, as differentiation of the Kibbey, Otter, and Heath Formations is not possible there.

The work of Maughan and Roberts (1967) has formed the basis of nomenclature for all subsequent work in Montana. Differences of opinion have recently arisen again, however, regarding the placement of the system boundary. Maughan and Roberts (1967) acknowledged that fossil evidence for a Pennsylvanian age in the Tyler was limited, but nonetheless contended that the unconformity at the base of the Tyler represented the best horizon in the field for locating the boundary. Brachiopod, conodont, and foraminifera biostratigraphy has recently indicated, however, that the system boundary in central Montana is located within the Alaska Bench Limestone of the Amsden Group, well above the horizon advocated by Maughan and Roberts (1967; Davis, 1983; Dutro et al., 1984; Wardlaw and Pecora, 1985).

Relationship of the Big Snowy Formation to the underlying Mission Canyon Limestone

The Mission Canyon Limestone is a prominent cliff- and ridge-forming limestone of middle Osage to middle Meramec age (Sando, 1975). This unit is present in much of Montana, but is thin or absent locally and north of 47°N latitude, where it has been removed by pre-Jurassic and/or Tertiary uplift and erosion. In southwestern, central, and eastern Montana the formation is overlain by the Big Snowy Group or Formation, while farther south the Amsden Formation rests with marked disconformity on the Mission Canyon.

Mission Canyon time was characterized by several fluctuations of sea level, resulting in the deposition of cyclically interbedded dolomite and limestone, with local anhydrite intervals in the upper half of the formation (Roberts, 1966). Thickness trends in the Mission Canyon correspond to those of the Big Snowy, being thickest in the Snowcrest and Big Snowy troughs, and thinning to the north and south (Craig, 1972).

Solution breccia zones are conspicuous features in the upper Mission Canyon and can be traced throughout most of the mountain ranges in southwestern Montana, as well as in the subsurface of the Big Snowy-Williston basin area. In the latter region the upper part of the Mission Canyon is replaced by the Charles Formation (Sloss, 1952). Several brecciated zones in nearby surface exposures of the upper Madison Limestone correlate with unaltered anyhydrite zones in the subsurface, indicating a direct relationship between Late Cretaceous and early Tertiary uplifts and the areal extent of the solution breccia zones (Severson, 1952; Nordquist, 1953; Roberts, 1966).

Karst features, such as sinkholes and enlarged joints, perpendicular and parallel to bedding, are the two most commonly observed features at or near the Mission Canyon-Big Snowy contact in southern and southwestern Montana; caves occur less frequently (Sando, 1974). Features observed along the Mission Canyon-Big Snowy contact generally substantiate an erosional unconformity in southwestern Montana. Irregular contacts, erosional thinning, and silicified limestones in the uppermost Mission Canyon, and limestone pebble conglomerates in the lowermost Kibbey are reported at various localities within the Snowcrest trough area (Scholten et al., 1955; Blake, 1959; Pecora, 1981; Guthrie, 1984). Workers in the Snowcrest Range area usually have argued against the presence of an unconformable relationship here; however exposures of this relationship are very poor.

Big Snowy trough

Kibbey Formation

The Kibbey Formation, the oldest and most widespread of the three formations in the Big Snowy Group in Montana, represents nearshore deposition at the leading edge of the transgressing Big Snowy sea. In the Big Snowy trough and Williston basin areas the Kibbey is divided into three informal members (Harris, 1972).

The lower member consists predominantly of red and green shales, with thin to thick sandstone and gypsum lenses. Sand, derived from the craton, accumulated in high energy shoreline deposits, while deposition of finer grained detritus was occurring in intertidal and very shallow subtidal environments. Periodic restrictions of marine circulation in the trough, related to tectonic instabilities and/or fine-scale eustatic sea level fluctuations, resulted in gypsum deposition locally (Ballard, 1964, Sando, 1976).

The subsequent diminution of the supply of coarse clastic material from the cratonic interior promoted deposition of the succeeding dolomites, evaporites, and bioclastic limestones which characterize the middle member (Smith and Gilmour, 1979). A thick sequence of sandstones, interbedded red and gray shales, and subordinate lenses of dolomite make up the upper member, completing the threemember series. The sandstones of this upper member were deposited in a high energy shoreline environment concurrent with deposition of shales in the deeper, quieter waters in the central part of the trough (Ballard, 1964; Smith and Gilmour, 1979).

The exact age of the Kibbey is unknown because of the paucity of identifiable fossils in the formation, but the stratigraphic position argues for a late Meramec to middle Chester age (Fig. 8; Sando et al., 1975).

Otter Formation

The Kibbey Formation is conformably overlain by the Otter Formation. The gradational transition is best exposed at Durfee Creek dome, in the Big Snowy Mountains, where red sandstones of the upper Kibbey member intertongue with gray shales of the basal Otter over a 10 to 20 foot interval (Harris, 1972). The Otter, assigned a Chester age, is characterized by a lower shale and limestone sequence, a middle limestone and evaporite sequence, and an upper black to green shale succession. A deeper water, normal marine depositional environment, punctuated by a brief period of very minor clastic input, is envisioned during Otter deposition (Harris, 1972).

Heath Formation

The contact with the overlying Heath Formation is set at an abrupt color change in the shales from bright coppery green to black, which is generally coincident with the occurrence of a limestone bed rich in productid brachiopods (Easton, 1962). In some areas the color change is less abrupt, occurring over a 35 to 100 foot interval, and the top of the Otter is placed at the horizon above which the shale and limestone litholgy typical of the Otter is replaced by a predominance of black shales common to the Heath (Smith and Gilmour, 1979).

The Heath Formation records the climax of marine transgression in the Big Snowy trough in late Chester time, and the rapid withdrawl of the the sea which followed (Fig. 9). The Heath consists chiefly of dark gray to black carbonaceous claystones and mudstones, which commonly are fissile on outcrop, and interbedded thin to massive beds of dark gray, argillaceous limestones and dolomites (Maughan, 1984); both the shales and limestones tend to be petroliferous. Coarse, terrigenous material, common to the Heath Formation, distinguishes it from the less clastic-enriched Otter Formation below.

The lower part of the Heath was deposited in calm, relatively deep water, while the erosionally thinned uppermost part of the formation, distinguished by isolated gypsum beds, reflects the shallow and partially restricted conditions prevalent during rapid withdrawl of the sea in latest Chester time (Maughan, 1984; Sando, 1976).

The top of the Heath Formation is placed at a regional unconformity on which rest uppermost Mississippian Tyler Channel sandstones, or sandstones, limestones, and silty shales of the Cameron Creek Formation (Fanshawe, 1978).

The Big Snowy Group is generally considered to be representative of a deepening upward sequence coincident with eastward transgression of the Big Snowy sea. This vertical change is also observed laterally in both the Big Snowy and Snowcrest troughs, suggesting that the Big Snowy units represent a classic diachronic sequence.

Several points of evidence suggest that the Kibbey, Otter, and Heath Formations are, at least in part, facies equivalents of one another (Fig. 11). First, the contacts between the three formations are gradational over several tens of feet, and commonly intertongue throughout the depositional basin (Maughan and Roberts, 1967). Exceptions to this are noted at the basin margins, where fluctuations in the transgression resulted in the development of local disconformities.

Second, biostratigraphic data and stratigraphic relationships indicate that the Kibbey is oldest near the Idaho-Montana border, and youngest in the eastern end of the Big Snowy trough (Fig. 9; Sando, 1976). This age variation helps to explain the areal extent and thickness patterns of each of the formations in the Big Snowy Group. The Kibbey is the most widespread of the three units and

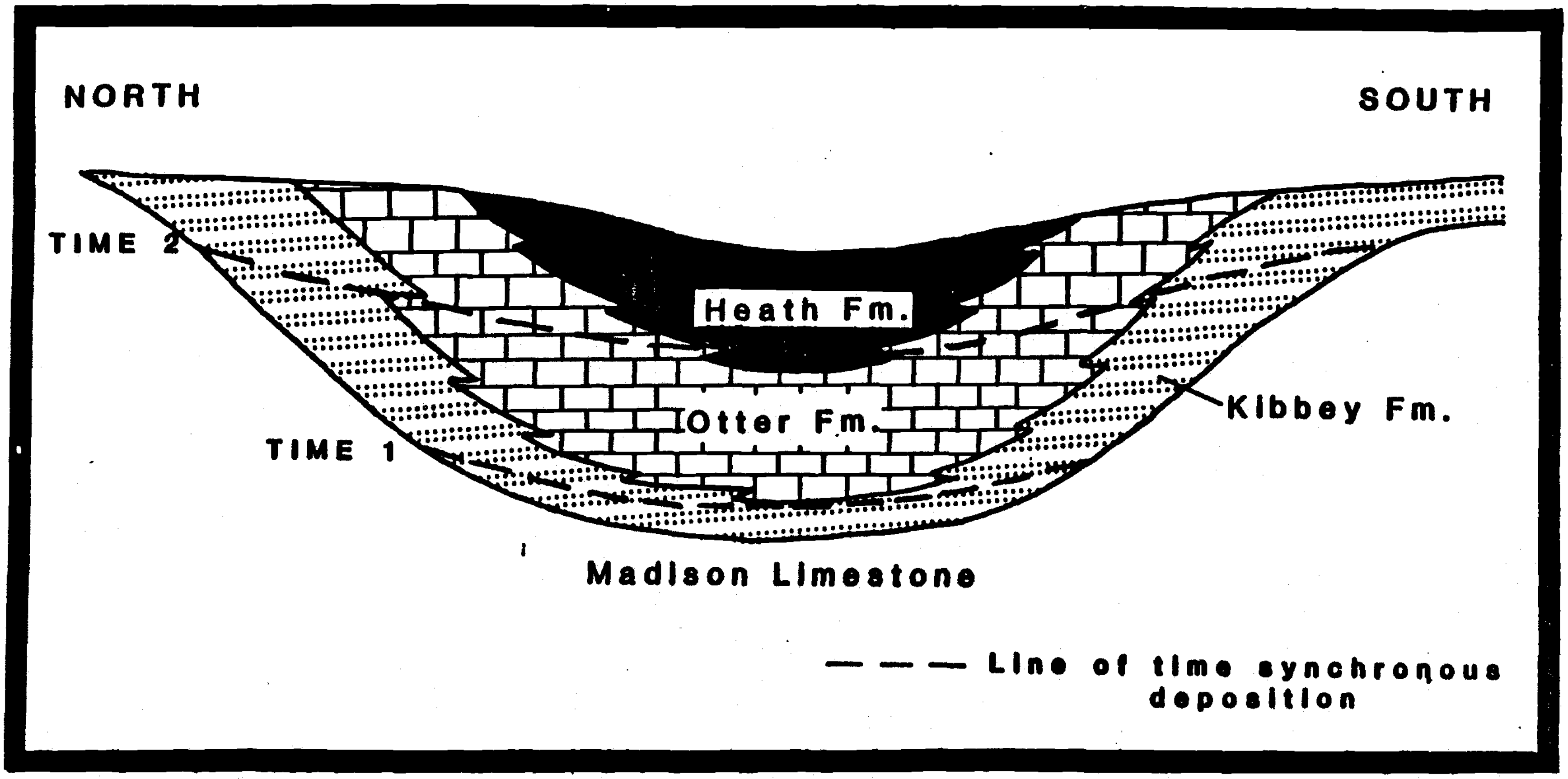


Figure 11. Schematic cross section across the Big Snowy trough, showing gross facies relationships and diachronic nature of the Big Snowy Group formations. Lithologies are generalized (from Harris, 1972).

is thickest along the basin margins, whereas the Heath is the most restricted areally, but is thickest in the center of the basin (Harris, 1972). The Heath and Otter are both observed to thin laterally in almost direct proportion to thickening of the Kibbey toward the paleoshore (Maughan, 1984).

Snowcrest trough

The Snowcrest trough is recognized as a unique entity, intimately related structurally and temporally to the Big Snowy trough, and, yet, bearing a relatively unique Upper Mississippian rock sequence.

Several workers mapped the Carboniferous age rocks in southwestern Montana in the early fifties (Honkala, 1949; Keenmon, 1950; Kupsch, 1950; Mann, 1950, Gealy, 1953), but only recently have geologists again directed their attention to this area. Oil exploration in this region has been minimal, probably because of the poor data base, complex structural fabric, and discouraging results of early wildcat wells. Recent work has resulted in the development of new stratigraphic nomenclature for the Upper Mississippian and Lower Pennsylvanian rocks in southwest Montana, and is providing insight into the relationship of the Big Snowy Formation in the Snowcrest trough and the Big Snowy Group in the Big Snowy trough.

Southwest of the Lombard arch region (Fig. 7) the unique stratigraphic identity of the Kibbey, Otter, and Heath Formations of central Montana becomes obscured. The lower and upper members of the Kibbey Formation thin over the Lombard arch and continue essentially unchanged to the southwest, whereas the middle member thins to a feather edge on the eastern side of the arch (Harris, 1972). The overlying Otter and Heath Formations also thin over the arch, but the individuality of each is lost as they pass laterally into a single unit dominated by dark gray limestone (Fig. 9).

Blake (1959) tentatively named this unit the Lombard facies of the upper Big Snowy Group because of its accessibility and well developed exposure near the abandoned Lombard railroad station, located approximately 15 miles south-southeast of Townsend, Montana, along the Missouri River. At this location the rocks are chiefly gray to black silty limestones with thinly laminated silty partings, and silty claystones. McMannis (1955) first recognized this unit in the Bridger Range, where he correlated it to both the Lombard section, to the northwest, and the type Big Snowy rocks in the Big Snowy trough.

Subsequent workers have reduced the Big Snowy Group in the Snowcrest trough to formational status, because the individual formations of the group cannot be mapped separately (Maughan and Roberts, 1967). Locally, the Otter Formation has been traced as far west as Three Forks (Terry, 1953), although west and southwest of the Castle Mountains area the percentage of silty limestone increases markedly at the expense of shale, making recognition of the type Otter and/or Heath Formations extremely tentative (Blake, 1959).

New Terminology

Most recent workers in this region have attempted to apply the type Big Snowy terminology to the Upper Mississippian rocks in their respective field areas, but the need for revision in the terminology for rocks at this stratigraphic level is mentioned by all. New stratigraphic nomenclature has been adopted by the U. S. Geological Survey for Upper Mississippian and Lower Pensylvanian strata in southwestern Montana and east-central Idaho to supplant the Big Snowy and Amsden Formations (Fig. 9; Wardlaw and Pecora, 1985). The new group is be called the Snowcrest Range Group, although, unfortunately, none of the type section localities are actually in this range. Sawtooth Mountain, in the southwestern part of the Snowcrest Range, is an ideal location to measure and describe rocks correlative to the Lombard Limestone facies of the Big Snowy Group, described by Blake (1959). The Lombard Limestone, the middle unit of the proposed Snowcrest Range Group could possibly be supplanted by the "Sawtooth Mountain Formation" or "Snowcrest Formation" to maintain integrity with the code of stratigraphic nomenclature.

<u>Kibbey Formation (revised) and Lombard Limestone</u>. The Kibbey Formation, assigned a middle Meramec age, is retained as the basal formation in the new group (Sando et al., 1985). This is conformably overlain by the Lombard Limestone (new), which is correlative to the Otter and Heath Formations, and part of the Tyler Formation of central Montana. The Lombard consists of a series of thin- to thick-bedded lime mudstones, wackestones, and

packstones with silty to limy shale interbeds and partings (Wardlaw and Pecora, 1985). A late Meramec to Chester age is assigned to this unit. At some localities a lower and upper member can be recognized, but this differentiation is lost to the west.

<u>Conover Ranch</u>. The uppermost unit is the Conover Ranch Formation, correlative to the upper part of the Tyler Formation and the Alaska Bench Limestone in central Montana (Fig. 9). Within the Snowcrest trough, it is, in part, temporally equivalent to the lowermost part of the Pennsylvanian Quadrant Formation. This unit displays a more variable lithology, consisting of pale reddish mudstones, and subordinate marine limestone and sandstone beds which crop out discontinuously. Faunal evidence suggests a late Chester age for these rocks, although the unit becomes progressively younger to the north and northeast, ultimately acquiring an early Morrow age (Wardlaw and Pecora, 1985). It is, therefore, apparent that the Mississippian-Pennsylvanian boundary lies within the upper part of the Conover Ranch, because this unit is time equivalent with the Alaska Bench which is known to contain the system boundary in central Montana (Davis, 1983).

<u>Railroad Canyon Formation</u>. The Railroad Canyon is the new name proposed by the U. S. Geological Survey to supplant the Big Snowy Formation in easternmost Idaho (Wardlaw and Pecora, 1985). This formation, found only in the Beaverhead Range, consists of dark shales, limy mudstones, fossiliferous silty limestones, and clayey calcareous siltstones, with subordinate sandstones and conglomeratic

limestones. It is laterally equivalent to the upper half of the Snowcrest Range Group in southwestern Montana (Wardlaw and Pecora, 1985).

This report uses the terminology of Wardlaw and Pecora (1985) inasmuch as this nomenclature best conforms to the rock units described in this report.

Relationship of the Big Snowy Formation to the overlying Amsden Formation

The Big Snowy Group is overlain by the late Chester to Morrow Conover Ranch Formation and Amsden Group in the Snowcrest and Big Snowy troughs, respectively. The contact between these two groups varies, however, from conformable at the southwesternmost end of the Snowcrest trough to unconformable in the Big Snowy trough and northeastern end of the Snowcrest trough.

The unconformity is attributed to withdrawl of the Big Snowy sea to a position in southwestern Montana in late Chester time. This relatively short-lived marine regression was associated with sporadic, differential uplift in the Big Snowy trough (Sando, 1976). At some places in the Big Snowy trough deposition across the Big Snowy-Amsden boundary appears to have been continuous (Jensen and Carlson, 1972).

The Tyler Formation, distinguished in part by gray and red siltstones and sandstones, unconformably overlies the Big Snowy Group in central Montana (Maughan and Roberts, 1967). Upper Big Snowy rocks in the southern and central parts of the Snowcrest trough are overlain by the predominantly red sandstones, siltstones, and mudstones of the Conover Ranch Formation, the correlative of the Tyler Formation (fig. 9; Wardlaw and Pecora, 1985). The generally poor exposures in southwestern Montana have prevented agreement among investigators regarding the characteristics of this contact in the Snowcrest trough area southwest of the Bridger Range.

Recent work in the Blacktail Mountains has suggested that the Conover Ranch conformably rests upon the Lombard Limestone at the southwestern end of the Snowcrest trough (fig. 9; Pecora, 1981). In the Beaverhead Mountains, the Railroad Canyon Formation, correlative to the upper half of the Lombard Limestone, is conformably overlain by the Bluebird Mountain Formation. The lower part of the Bluebird Mountain is correlative to the Conover Ranch, and like the Conover Ranch, represents a flood of inner craton-derived sand during latest Chester time (Skipp et al., 1979; Wardlaw and Pecora, 1985). The conformity-unconformity transition must, therefore, occur somewhere within the central or south-western parts of the Snowcrest trough.

RELATIONSHIP OF THE KIBBEY FORMATION TO THE UNDERLYING MISSION CANYON LIMESTONE

Description

The Mission Canyon Limestone crops out throughout most of the thesis area, although southeastward thrusting and associated folding has locally removed and/or added section. Rocks of the Mission Canyon Limestone and Snowcrest Range Group make up most of the western flank of the Snowcrest Range. The most complete Mission Canyon section crops out at the southwestern end of the range, near Red Rock River (NW 1/4, section 21, T. 13 S., R. 7 W.), approximately 6.4 miles due east-northeast of Lima, Montana.

At this location, 1,327 feet of Mission Canyon are exposed in a S. 27 E.-striking anticline. The limestones and dolomites in the lower half of the formation crop out discontinuously and vary from massive to crudely medium- to thick-bedded. The exposed upper half, 448 feet thick, is characterized by well developed, thin to very thick beds which display more lateral continuity than those below. A poorly exposed solution collapse breccia, which can be traced laterally for almost one half mile, occurs midway up the section. In addition to a sharp increase in slope, the bedding character of the carbonates changes dramatically across this breccia zone; thus the breccia acts as a dividing line between the lower and upper sections.

The lower section, approximately 540 feet thick, is composed of biopelmicrites, sparse biomicrites, echinoid biosparites, and micrites. This diversity of lithologies (determined by petrographic analysis) is commonly difficult to recognize in the field, as many of the rocks are partly to completely recrystallized and most are extensively fractured. As a result, these rocks are classified in the field as sparsely fossiliferous wackestones, mudstones, and recrystallized carbonates (Dunham, 1962). Fresh surface colors vary from grayish brown (5 YR 4/2), to light brownish gray (5 YR 6/1), to pale brown (5 YR 5/2), but the majority of the rocks weather to either light gray (N7) or medium light gray (N6). The uppermost Mission Canyon is covered and estimated to be 264 feet thick.

The upper section is less diverse lithologically, consisting of a thickening upward sequence of washed biomicrites and sparse biomicrites, with thin, subordinate dolomite and/or dolomitic limestone interbeds. This sequence crops out as pronounced, laterally continuous to discontinuous, planar to slightly undulatory ledges. Cliffs occur locally because of the steep, southeastward dip of the beds on the east-facing hillside. The top of this exposed sequence ends abruptly at the base of the hillside, passing into a wide, covered saddle underlain by Kibbey, Lombard, and Amsden lithologies (fig. 4). This covered, saddle-forming interval is ubiquitous throughout the southwestern end of the Snowcrest Range.

Approximately 543 stratigraphic feet of cover separate the highest Mission Canyon exposure from the lowest Lombard exposure. Most of the gray to dark gray soil and float across this interval is of Mission Canyon and Lombard affinity; however, a narrow, diffuse zone of admixed buff to grayish orange soil occurs midway between the two exposures in the saddle area (NE 1/4, section 21, T. 13 S., R. 7 W.). This narrow zone probably represents the non-resistant Kibbey Sandstone.

Because the top of the Mission Canyon here is obscured by float and/or soil development, analysis of the contact with the Kibbey is not possible. The solution breccia zone is significant, however, as stratigraphically restricted carbonate breccia zones are common in the upper two-thirds of the Mission Canyon in the western Rocky Mountains region, and can often be utilized as regional stratigraphic markers (Sando, 1968, 1974; Roberts, 1979). Solution breccias have been reported as low as 600 feet below the top of the Mission Canyon in the Bridger Range (Guthrie, 1984), and from 80 to 360 feet below the top in northern Wyoming mountain ranges (Sando, 1974). Pecora (1981) reported the occurrence of a 70-foot-thick breccia zone approximately 250 feet below the Mission Canyon-Kibbey contact in the Blacktail Mountains, northwest of the thesis area.

The solution breccia zone at the Red Rock River section occurs 448 feet below the uppermost exposed Mission Canyon ledge (712 feet below the inferred Mission Canyon-Kibbey contact). The thickness of the solution breccia varies laterally, primarily involving assignment of the upper contact, but averages 33 feet. The base is sharp and planar, as the underlying limestone lithology terminates abruptly against the poorly exposed solution breccia interval, coincident with a moderately sharp change in slope and soil color. Most of the unit is covered, but trenching and exploration in and adjacent to gopher holes reveals the underlying brecciated lithology. The pale yellowish orange (10 YR 8/6) to moderate yellowish brown (10 YR 5/4) soil is typically thin. The underlying lithology is dominated by limonite- and/or goethite-stained limestone solution breccia. Vuggy porosity is ubiquitous, although the amount of porosity varies dramatically, from 8 to 40 percent, over a very short distance, both laterally and vertically. Many of the irregular vugs exceed 1/2 inch in diameter and are filled with botryoidal calcite masses. Variably sized, subangular to angular limestone and dolostone fragments are common, although many have been leached, creating a honeycomb-like texture composed of the surviving coarse interclast spar cement.

Petrographic analysis reveals that the limestone clasts are all recrystallized, unfossiliferous(?) limestone (some dolomitic), containing six percent medium to coarse quartz silt. All of the breccia clasts are characterized by a light yellow to light orangish red iron stain which intensifies toward the outer edge of the clasts. Analysis with reflected light indicates that the stain is goethite and/or hematite, the latter occurring chiefly along the clast margins. Additionally, the edges of many of the coarse calcite cement crystals between the angular clasts are iron stained. The vuggy porosity is restricted to the clasts. The cement is predominantly coarse, mosaic, limpid sparry calcite which, upon preferential solution of the breccia clasts, creates the polygonal, honeycomb-like texture seen in hand sample.

Clear sparry calcite cement does not occupy the entire interclast area. Fine, angular limestone fragments commonly surround the larger limestone clasts. Locally, pockets of subrounded, monocrystalline quartz silt and very fine sand (total 48 percent) and iron-stained microspar and pseudospar (total 42 percent) are present. Intergranular and vuggy porosity make up 15 percent of this matrix. Detrital zircon and chert occur rarely.

Near the top of the solution zone the breccias grade upward into thin, fractured limestone beds with thin, pale red (10 R 6/2) to pale reddish brown (10 R 5/4) dolomitic siltstone interbeds. Monocrystalline quartz and dolomite make up 63 and 30 percent of the total constituents, respectively, followed by six percent chert and one percent polycrystalline quartz. In contrast to the absence of heavy minerals in the lower part of the breccia zone, a diverse assemblage occurs in the red siltstones. Magnetite, tourmaline, zircon, green hornblende, leucoxene (after ilmenite?), and augite(?) all occur as scattered grains in the predominantly quartzose framework.

The diameters of the quartz grains range from 0.02 mm (medium silt) to 0.28 mm (fine sand), most occurring in the very fine sand size fraction (averaging 0.10 mm diameter). A similar range of values characterizes the chert fraction, but the chert grains display a subrounded to rounded habit and have high sphericity values (0.8-0.9), in contrast to the quartz grains which are typically subangular to subrounded and more tabular/elongate (sphericity = 0.5-0.7).

Dolomite is present as a dirty, coarse, mosaic matrix and cement. Poorly developed, limpid to dusty dolomite rhombs occur locally. In addition to the cementing dolomite, numerous syntaxial quartz overgrowths cement many of the framework constituents.

Hematite staining is ubiquitous, but usually incomplete, on the edges of the framework elements; the iron stain never occurs within the quartz or chert grains. A very complete and intense peripheral iron stain locally colors both the framework constituents and the dolomitic matrix.

Laminations are very rare and usually irregular. Most of these thin siltstones are massive, but display irregular banding patterns because of local variations in hematite concentration. Upsection the highest thin siltstone bed is overlain by limestones which become progressively less fractured, ultimately passing into the thin to medium beds which characterize the lower part of the upper half of of the Mission Canyon sequence.

Approximately 12.7 miles to the northeast, at Clover Divide, the uppermost Mission Canyon is exposed on the southeast flank of a large, northeast-trending anticline (NW 1/4, section 23, T. 12 S., R. 6 W.). The Mission Canyon here is exposed as a series of ledges and cliffs exposed by antecedent stream erosion and road construction normal to the strike of the anticlinal structure. Elsewhere this section is predominantly covered and vegetated. Late Cretaceous to early Tertiary uplift and associated subaerial exposure has resulted in the development of a modern karst topography, including limestone spires or hoodoos, solution pits, small caves, and extensive vuggy porosity, which overprint the paleokarst deposits here.

The absence of any beds or soil indicative of the Kibbey Formation at this locale, and the presence of a stream valley which contours the inferred Mission Canyon-Lombard contact, suggests that the Kibbey has been faulted out in this area. The lower 1,032 feet of the 2,023 foot thick Lombard section here, superposed on the Mission Canyon, is believed to be fault thickened (Zieglar, 1954; Perry, 1983; this report, appendix A). Paleokarst features and diagnostic corals in the uppermost limestone beds of the Mission Canyon suggest that very little Mission Canyon Limestone is missing beyond that originally lost to subaerial exposure and erosion in Meramecian time.

The upper formal member of the Mission Canyon Limestone in southern Montana and northern Wyoming is the Bull Ridge Member. This member is characterized by a basal, silty to dolomitic, limestone solution breccia. This grades upward into a sequence of fossiliferous limestones and dolomites, commonly containing many karst elements, including enlarged joints, caves, sinkholes, and solution breccias (Sando, 1968, 1972, 1974a,b). The partial Mission Canyon exposure at Clover Divide similarly consists of a thick sequence of poorly to well exposed, sorted biosparites, and sparse and packed biomicrites, with subordinate silty dolostone and calcareous siltstone interbeds. Biotic constituents include echinoid ossicles and plate fragments, brachiopods, pelecypods, foraminifera, ostracodes, trilobites, corals, and bryozoan debris. Pellets and intraclasts occur locally. Within this limestone sequence, solution breccias, pisolitic limestones, collapse structures, and large, discontinuous solution cavities filled with massive, pale yellowish orange to moderate red, argillaceous and dolomitic siltstones and silty carbonate breccias are all common.

The uppermost fossiliferous limestone beds contain two significant corals, _Diphyphyllum_ sp. and _Vesiculophyllum_ sp. (W. J. Sando, personal communication, 1985) of Osagean to

Meramecian age. The uppermost fossiliferous limestone beds in the Bull Ridge Member type section also contain, and are characterized by Diphyphyllum sp. which is diagnostic of Coral Zone IIIA (early Meramecian; Sando, 1968, 1980a, 1982).

The solution breccias display a complex genesis, involving several periods of brecciation, neomorphism, and recrystallization in both the limestone clasts and surrounding calcareous matrix. Dolomite content in the matrix varies, but is characteristically very low (<10 percent). Likewise, the quartz fraction is generally subordinate to the mosaic pseudospar and sparry calcite. Most of the quartz present is coarse silt (average diameter = 0.05 mm), although coarse sand quartz grains (up to 0.8 mm) occur rarely. X-ray diffraction analysis of the matrix indicates the additional presence of kaolinite. While the quartz fraction is subordinate in the matrix, many of the large, sparry calcite-filled fractures contain a significant amount of monocrystalline, angular to subrounded, quartzose silt.

In outcrop, the small, randomly oriented limestone blocks and variably rounded clasts show little ordered vertical variation in size within the breccias. Many of the clasts have altered to a soft, grayish orange (10 YR 7/4) clay material which locally is weathered out, creating irregular vugs. In several places the honeycomb-like vuggy habit, similar to that described in the solution breccia at the Red Rock River section, is very pronounced. In contrast, however, the vugs here tend to be lined with clays rather than botryoidal calcite. At a few exposures the clasts display a crude reverse grading, passing upward into unfractured limestone beds.

These solution breccias are seldom stratigraphically bound and rarely display moderately disturbed, but intact, limestone interbeds of variable thickness. Unlike the solitary solution breccia zone found at Red Rock River, the myriad of solution breccias and other karst features have disrupted much of the bedding at Clover Divide.

Discontinuous solution cavities are especially common. Massive, silty dolostones and limestones, and brecciated calcareous siltstones and subordinate sandstones typically fill these cavities. Many of these karst fills are very deeply weathered and exhibit a pale yellowish orange (10 YR 8/6) to moderate red (5 R 4/6) color. Calcite is more common than dolomite, and quartz typically is slightly subordinate to the microspar and pseudospar, although quartz locally makes up a more significant part of the rock. Chert is always rare. As in the matrix of the solution breccias, kaolinite is present in these rocks. Muscovite, is a common accessory mineral, succeeded by rare zircon and epidote grains. Small, irregular patches of coarse sparry calcite occur locally, and may represent recrystallized mollusks or some other indeterminate bioclast.

Collapse structures are ubiquitous and several excellent examples can be found within the uppermost Mission Canyon outcrops. Bedding is commonly fractured, distorted, faulted, and/or missing from solution of underlying and overlying units and subsequent collapse and flowage. The range in size of the brecciated limestone fragments is wide, and sorting is very poor. At several exposures columns of large, angular limestone blocks surrounded by contorted, finely brecciated silty limestone, dissect or disrupt the otherwise intact, well bedded limestones below (fig. 12).

Sinkholes, characterized by steep-walled, widening-upward shapes and predominate red sandstone, siltstone, and/or shale infill, are commonly found throughout south-central Montana and northern Wyoming (Sando, 1974). These paleokarst features, however, were not recognized at Clover Divide, or elsewhere in the range.

The actual contact between the Mission Canyon Limestone and the Kibbey Formation cannot be observed anywhere in the Snowcrest Range because of faulting and the non-resistant character of the Kibbey. The presence of solution breccia zones, collapse structures, and solution cavities along discrete stratigraphic horizons within Meramecian limestones and subordinate dolomites (uppermost Mission Canyon) suggest that a period of subaerial exposure and solution by meteoric waters percolating through the carbonates occurred subsequent to Mission Canyon deposition, but before Kibbey or Lombard deposition.

Exposure of this contact is also poor at Sheep Creek Canyon, in the Blacktail Mountains, but an abrupt transition from ledge-forming, fossiliferous limestone to non-resistant, siltstone and silty dolostone does occur. Because of the predominantly covered habit of the Kibbey, specific relationships between the two units along the contact cannot be determined. The uppermost Mission Canyon bed displays a discontinuous outcrop habit along strike, however, and locally the grayish orange (10 YR 7/4) to moderate yellowish brown (10 YR 5/4) soil cover, overlying the vertical limestone bed, appears to fill the gap between ledges. The gentle

Figure 12. Solution collapse breccia at Clover Divide. Note large coherent limestone blocks "floating" in sandy limestone to dolostone matrix. Silty limestone bed is locally truncated and folded by collapse structure. Hammer at left edge of breccia for scale.

profile of the hillside does not exclude the possibility that the grayish orange cover is not in situ, and occurs in these gaps because of normal surface erosion, weathering, and transport processes. In addition to the sharp contact, Pecora (1981) has located one exposure in this area characterized by a dusky to moderate red quartz conglomerate with a silty matrix which overlies Mission Canyon limestones.

Interpretation

The poor to non-existent exposure of the Mission Canyon-Kibbey contact in the Snowcrest Range precludes precise description of the depositional relationship between these two units in the thesis area. Exposure in the Blacktail Mountains, and the presence of paleokarst elements in the uppermost part of the Mission Canyon exposed in the southern part of the Snowcrest Range, however, suggest complete withdrawl of the Madison sea from the thesis area in late early Meramecian to early middle Meramecian time.

The Mission Canyon Limestone in southern Montana and northern Wyoming is divided into three members. These members, in ascending order, are the lower limestone member, the middle cliffy member, and the Bull Ridge Member (Sando, 1972). The middle cliffy member is characterized by a ubiquitous, 25 to 50-foot-thick, basal solution breccia ("lower solution zone" of Sando, 1967), overlain by a variable sequence of cliff-forming limestones. The lower limestone member lacks solution breccia zones, is commonly thick-bedded, and contains a sparse fossil assemblage. The uppermost member, the Bull Ridge Member, also contains a basal solution breccia ("upper solution zone"), 10 to 25 feet thick, but is overlain by a sequence of brecciated fossiliferous limestones containing a diverse assemblage of early Meramecian fossils (Diphyphyllum Zone or Coral Zone IIIA); several thin terrigenous intervals commonly occur within the limestone sequence, as well (Sando, 1974).

The Mission Canyon Limestone in the northern and central parts of the Snowcrest Range is structurally complicated by one or more thrust faults which variably superpose slivers of Mission Canyon against Lombard Limestone, eliminating the uppermost Mission Canyon, and/or Kibbey, and/or lowermost Lombard from the exposed upper Paleozoic sequence. The two partial Mission Canyon exposures in the southern part of the range, howver, can be schematically combined to create a nearly complete section, which can be subdivided into three sequences correlative with the Mission Canyon type members.

The lithology and bedding habit of the lower and upper exposed parts, respectively, of the Mission Canyon sequence at Red Rock River, separated by a medial solution breccia, can be informally correlated to the lower limestone and middle cliffy members of the type Mission Canyon. The sequence exposed at Clover Divide can, in turn, be correlated with the Bull Ridge Member, based on the fossiliferous limestone and subordinate dolomite sequence containing _Diphyphyllum_ sp. and _Vesiculophyllum_ sp., with local siltstone and silty limestone interbeds. Given its stratigraphic position, apparently unfaulted setting, and overall less resistant character, the thick covered interval between the uppermost and lowermost exposed Mission Canyon and Lombard, respectively, at the Red Rock River section, is also inferred to be correlative with the Bull Ridge Member, although its exact thickness is unknown.

The presence of Diphyphyllum sp. and Vesiculophyllum sp. in the uppermost Mission Canyon limestones indicates that shallow marine deposition was still occurring in this area during early Meramecian time (Coral Zone IIIA) and possibly into early middle to middle Meramecian time (Coral Zones IIIB and C; Sando, 1980; Sando and Bamber, 1979). These ages coincide with those of the upper part of the Bull Ridge Member type section on the northern part of the Paleozoic Wyoming platform. Deposition was ongoing to the west, in the present Tendoy Range area, into middle Meramecian to early late Meramecian time (Gutschick et al., 1983, p. 714), but had ceased to the east, near Livingston, Montana, much sooner, possibly by early Meramecian time (Sandberg et al., 1980). Interpolation between these two west-east data points, and a minimum date (late early Meramecian) of complete withdrawl of the sea in the southwestern end of the Snowcrest trough, in the present Snowcrest Range area, suggest that a minimum amount of Mission Canyon has been faulted out at Clover Divide. Therefore, the paleokarst features present in the Bull Ridge equivalent here can be directly related to withdrawl of the Madison sea and subsequent transgression of the Big Snowy sea.

The timing of the development of the solution features observed in the Snowcrest Range is difficult to determine. In his study of the Madison Group in the Livingston, Montana, area, Roberts (1966) noted both laterally continuous solution breccias and discontinuous, stratigraphically unrestricted solution features. The former were attributed to solution of evaporite deposits and subsequent collapse of overlying and interbedded limestones, while the latter were classified as karst deposits. Roberts hypothesized that the karst deposits developed during a post-Mission Canyon, pre-Amsden period of uplift and subaerial erosion, and that the laterally continuous solution breccias formed later, during Late Cretaceous and early Tertiary uplift. Analysis of the the clay mineralogies of the matrix of the karst deposits and solution breccias revealed a predominance of kaolinite and illite, respectively. Therefore, the kaolinite suggests extended weathering of ancient soils on the subaerially exposed surface of the Mission Canyon, while illite indicates incipient marine deposition without alteration during uplift or brecciation (Roberts, 1966).

Subsequent studies elsewhere in the Mission Canyon present different results and, therefore, different conclusions (McCaleb and Wayhan, 1969; Sando, 1974). Clay mineralogy analysis of the aforementioned deposits in a Mission Canyon-Amsden sequence at the northern end of the Bighorn Basin, in north-central Wyoming, shows that illite is the only clay mineral present in the matrix of both types of deposits (McCaleb and Wayhan, 1969). This points to a common event, which occurred in post-Mission Canyon, pre-Amsden time.

X-ray diffraction analysis of the karst deposits in the Bull Ridge equivalent at Clover Divide indicates the exclusive presence of kaolinite in the matrix. Similar analysis of the solution breccia at Red Rock River, however, is inconclusive. Sando (1974) advocates a common age and origin of the solution breccias and karst features in the Mission Canyon of southern Montan and northern Wyoming. The solution breccia at Red Rock River, however, may have developed during post-Mission Canyon, pre-Kibbey subaerial exposure, or following Late Cretaceous-early Tertiary uplift. Given either origin, the terrigenous fraction of the solution breccia must be part of the original depositional sequence, and the brecciation attributed to solution of an evaporite sequence by phreatic freshwater, followed by collapse of the roof rock and thin limestone interbeds.

In contrast, karst development and infilling in the uppermost Mission Canyon at Clover Divide probably occurred during post-Mission Canyon, pre-Kibbey time. Discontinuous, and commonly irregular, solution cavities, solution breccias, and collapse breccias, with a hematite-stained matrix of calcite and quartzose silt and sand, suggest a karst origin for these features. The lack of an obvious connection to the surface, and the presence of kaolinite in the yellowish red to red matrix support this hypothesis.

The locally abundant quartz silt and sand in the matrix provide evidence that the karst features developed prior to deposition of the Kibbey Formation, as these terrigenous matrix constituents are thought to be derived from the Kibbey. Rapid infilling of the open, uncemented or incompletely cemented solution cavities with reworked soil and unconsolidated Kibbey clastics would account for the massive character of the matrix, as well.

The brecciated silty limestones and calcareous siltstones were probably part of the original shallow marine depositional sequence, as Sando (1974) has noted in north-central Wyoming.

Large solution channels, filled with red Kibbey siltstones, sandstones, and subordinate dolostones, occur in the uppermost Mission Canyon northwest of the thesis area, in the Horse Prairie area. These are interpreted as solution and collapse structures which developed along joint systems during post-Mission Canyon, pre-Kibbey uplift and subaerial exposure (W. J. Goodhue, personal communication, 1985). Solution breccias are also reported in this region and just west, in the Armstead anticline area. In both areas the Mission Canyon is additionally capped by a silicified solution breccia, up to 70 feet thick (Hildreth, 1981).

North and south of the thesis area, on the margins of the upper Paleozoic Snowcrest trough, red sandstones and siltstones of the basal Amsden Formation disconformably overlie the eroded Mission Canyon Limestone (Mann, 1950; Klepper et al., 1957; Sando et al., 1975; Lageson et al., 1979). At most of these locations the uppermost Mission Canyon, or Bull Ridge Member, is characterized by solution breccias, karst deposits, and an upper erosional surface with variable relief.

Within the Snowcrest Range and Blacktail Mountains, no evidence for intertonguing or a gradational transition between the Mission Canyon and Kibbey is recognized. Rather, a sharp transition with minor relief is found at Sheep Creek Canyon, indicating an abrupt change in depositional environment across the contact. Solution breccias are also common throughout the upper

60 feet of the Mission Canyon in the Blacktail Mountains, and the top of this Bull Ridge equivalent is truncated at a Meramecian erosional surface (Pecora, 1981). Farther east, in the Bridger Range, karst deposits are common, and three to six feet of relief occur along the Mission Canyon-Kibbey contact (Guthrie, 1984). Solution breccias in the Bridger Range also occur as much as 600 feet below the erosion surface.

In summary, karst deposits in the Bull Ridge Member equivalent in the Snowcrest Range indicate a period of subaerial exposure, beginning no earlier than late early Meramecian time, prior to onlap of the Kibbey Formation in late middle to late Meramecian time. The contact between these two formations is obscured or faulted out in the thesis area, but adequate exposure of the contact just northwest, in the Blacktail Mountains, supports this hypothesis. Comparison with the Mission Canyon-Kibbey (or -Amsden) contact and the lithology of the uppermost Mission Canyon (Bull Ridge Member) elsewhere in southwestern Montana also argues for complete withdrawl of the Madison sea from the western end of the Snowcrest trough in Meramecian time.

KIBBEY FORMATION

Introduction

The Kibbey Formation is covered throughout the Snowcrest Range, with the exception of an isolated outcrop at Sawtooth Mountain. A poorly exposed Kibbey section crops out along the north side of Sheep Creek Canyon, however, just north of the thesis area in the Blacktail Mountains. Two lithofacies can be recognized at this location, the upper of which can be correlated with the isolated exposure at Sawtooth Mountain. These two lithofacies are a lower, dolostone unit, and an upper, sandstone unit, deposited in upper intertidal-lower supratidal and lower intertidal to shallow subtidal environments, respectively. The dolostone and sandstone lithofacies can be correlated to similar dolomite-rich and sand- and silt-rich sequences, respectively, throughout southwestern Montana (Plate 2).

Description

Snowcrest Range

Thrusting has largely removed the non-resistant Kibbey Formation from the Paleozoic sequence exposed throughout the Snowcrest Range, although a characteristic grayish orange soil interval occurs locally in the southwestern part of the range. The only Kibbey outcrop recognized in the thesis area occurs at the base of a prominent hill (summit elevation 9,566 feet) underlain by Lombard Limestone, approximately one mile west of Sawtooth Mountain (SW 1/4, NE 1/4, NW 1/4, section 9, T. 12 S., R. 5 W.).

The characteristic covered Kibbey interval here is broken by a twelve foot thick series of discontinuous, medium-bedded, very pale orange (5 YR 8/2) and yellowish gray (5 Y 7/2), fine- to medium-grained quartz arenite ledges (fig. 13). This abbreviated ledge-forming sandstone sequence is laterally restricted, however, and crops out discontinuously for only several tens of yards along strike. This discontinuous habit may be the result of variable cement composition or slight variation in the degree of cementation. Weathering and fracturing of the medium, planar to slightly undulatory beds has created flaggy and slabby rubble, which surrounds the ledges and is scattered for several tens of feet down the hillside. Evidence of cross-bedding, ripples, grading, and bedding plane structures indicative of current/transport direction are absent.

Very thin, slightly undulatory laminations characterize the upper part of this unit, which weathers to grayish orange (10 YR 7/4), in contrast to the lower part which is typically massive to mottled, and weathers to a moderate brown (5 YR 4/4) color. The transitional character between these two units is difficult to discern because of the discontinuous outcrop habit of these sandstones, but appears to be gradational over an approximately two foot thick interval. Both units are well sorted quartz arenites, but variations in grain size and interstitial clay accompany and, in part, account for the textural variations observed in outcrop. Because of the significant textural differences between the lower and upper units, they will be discussed separately.

Detrital quartz grains make up both the framework and matrix of the lower unit. The coarser quartz fraction, which accounts for

Figure 13. Photograph of isolated Kibbey outcrop (foreground) at Sawtooth Mountain. Note the characteristic grayish orange color of the ledges and float, in contrast to the gray to grayish brown outcrops, float, and soil of the overlying Lombard Limestone (near snowbank). View is the the southwest, on northwest side of hill located just west of Sawtooth Mountain.

40 percent of the rock, is subangular to predominantly subrounded, and ranges from coarse silt (0.05 mm diameter) to medium sand (0.50 mm) size (fig. 14). Fine sand size grains, with an average diameter of 0.18 mm, predominate. Most of the coarse quartz grains (35 percent) are monocrystalline and unstrained, but undulose, polycrystalline quartz grains (stretched metamorphic quartz of Folk, 1980) make up four percent of the total constituents, succeeded by scarce, well rounded detrital chert grains (one percent). In addition, a few well rounded detrital orthoclase grains are locally present. No imbrication or pronounced shape fabric is recognized, as most of the detrital grains are moderately spherical (average = 0.7), although the subordinate elongate fraction (sphericity = 0.3-0.5) does display a crude orientation subparallel to bedding.

The matrix of this unit can be more appropriately considered as a secondary or subsidiary framework assemblage as it is almost identical mineralogically to the coarser framework quartz fraction. Chert is slightly more abundant, but the monocrystalline to polycrystalline quartz ratio is similar to that of the coarser quartz constituent. Overall, the framework and matrix quartz combine to make up greater than 90 percent of the total constituents. Aside from the finer grain size, averaging 0.03 mm diameter (medium silt), the matrix quartz is predominantly subangular and only moderately sorted (fig. 14). Indeterminate cryptocrystalline clay is ubiquitous between the matrix quartz grains, and composes up to eight percent of the total constituents. Most of this material displays a yellowish green color under plane

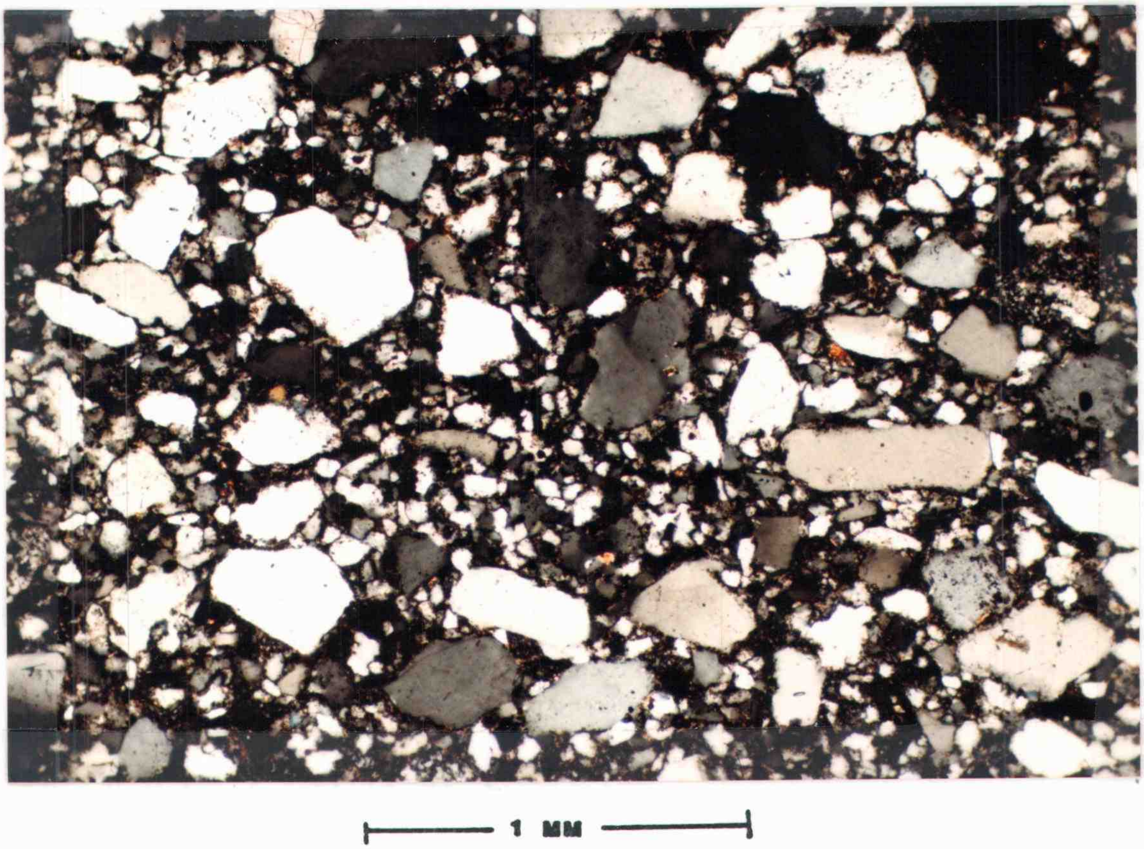


Figure 14. Bimodal sorting in quartz arenite of Kibbey Formation. Note syntaxial quartz overgrowths which cement most of the framework and matrix grains. Unit 3, lower part, Sawtooth Mountain section. Crossed nicols.

polarized light, but is pseudoisotropic under crossed nicols. Hematite is common as a localized stain on the interstitial clays, but also occurs as large clots and/or as irregular, microns-thick bands and lenses. Some of these hematite-rich bands display a geometry or distribution which suggests the former presence of some type of bivalved animal, such as a pelecypod or brachiopod. These bands are characterized by a lack of quartz grains and a high proportion of clays and finely disseminated hematite. Their origin is unknown, but bioturbation, concentration by migrating pore fluids, or ultimate bioclast replacement are possibilities.

In addition to the interstitial clays, most of the remaining original intergranular pore space is filled with euhedral, authigenic quartz crystals with characteristic pyramidal terminations; porosity and permeability are, therefore, very low (less than one percent). Additionally, a few subhedral authigenic quartz grains are present, which are surrounded by centrifugally-radiating, multiple growth rims. Very thin dustings of iron-stained clay outline the cessation of each period of overgrowth development. Other grains lack the internal clay dust rims, but display well developed centrifugally-radiating overgrowths. The origin of the pores in which many of these must have originated is uncertain, but many may have been sites of broken biotic constituents leached out by pore waters undersaturated with respect to calcium carbonate.

Calcite is rare to absent in this unit. Most of the matrix quartz grains are surrounded by optically continuous quartz overgrowths which cement the grains, while clay fills most of the remaining intergranular space, as previously mentioned The coarser quartz grains, on the other hand, are characteristically lacking syntaxial quartz overgrowths or have only partial overgrowths.

Heavy minerals are present in trace amounts only, but include magnetite, zircon, apatite, epidote, brown hornblende (lamprobalite?), and indeterminate orthopyroxene. Magnetite has largely altered to hematite and rare limonite.

In contrast to the random bimodal quartz distribution in the lower unit, the upper unit is laminated and contains a more uniform range of quartz grain sizes. One set of laminae is characterized by angular to subrounded, coarse quartz silt in framework support, with subordinate to rare interstitial clay and hematite. Optically continuous quartz overgrowths occupy most of the intergranular space and cement the quartz grains, which are relatively equant to slightly elongate. Substantially more undulose monocrystalline and polycrystalline quartz is present than in the lower unit, but this may be a function of the finer overall grain size.

Rare, extremely thin chlorite(?) fringes occur between some of the quartz grains, typically inhibiting overgrowth development; this clay coating is seldom found between overgrowths sharing a mutual contact. Large, scattered clots of hematite are common, rarely passing laterally into a diffuse network of iron-stained interstial clay and/or fine micas.

The other set of laminae, which are characteristically thinner, are finer grained, and contain appreciably more interstitial clay and hematite. Most of the angular to subangular, medium silt size quartz grains are monocrystalline and unstrained, in contrast to the higher concentration of strained grains in the alternating laminae. In addition, there are fewer equidimensional grains and more elongate or tabular grains. Syntaxial quartz overgrowths are common, as before, but most of the grains are entirely to predominantly surrounded by cryptocrystalline clays, possibly of a chloritic affinity. X-ray diffraction analyses indicate that some of the interstial clay may be kaolinite, but in amounts only at the limit of detection of the diffractometer. Fine, scattered muscovite flakes are moderately common in the matrix; most are bent and deformed between the framework grains, but all display original parallelism with respect to the inferred depositional surface. In contrast to the alternating laminae, iron-staining is ubiquitous and typically more intense on the interstitial argillaceous material.

Both sets of laminae contain a similar heavy mineral suite, including magnetite, zircon, epidote, muscovite, and subordinate apatite, tourmaline, and hornblende. The hematite which stains the matrix was largely derived from the alteration of the detrital magnetite and hornblende. Most of the the heavies are subrounded, with the exception of the hornblende and muscovite, which are subangular to angular.

The transition between laminae is sharp, reflecting the abrupt decrease or increase of interstitial clay and the change in grain size and sphericity. Many of the laminae display a broad wavelength, low amplitude pinching and swelling habit, but are laterally continuous. The thinner, clay-rich laminae commonly tend to intersect or are abruptly deflected coincident with a rapid thickening of the lighter colored, clay-deficient laminae, creating a locally discontinuous character to the latter laminae.

In outcrop, the laminated habit commonly grades laterally into a massive habit. Where thin, vertical fractures cross-cut the laminations, the laminae are not deflected, indicating that the fracturing event occurred after lithification. These fractures are filled with mosaic and/or inwardly radiating sparry calcite, but all contain a thin hematite stain along the outer edge of the fracture wall, separating the calcite fill from the framework elements. This argues for the introduction of iron-rich waters, which may have produced the iron stain on the interstitial clay, following and/or during fracturing, but prior to deposition of the calcite fill.

Blacktail Mountains

The Kibbey Formation is more completely exposed on the north side of Sheep Creek Canyon, in the northern Blacktail Mountains. The 118.5 foot thick Kibbey section here is poorly exposed along a gentle slope which is transitional between the steeper slopes underlain by Lombard Limestone to the west, and the cliff-forming Mission Canyon Limestone on the east. Despite the poor exposure quality, two lithofacies can be discerned, a lower dolostone and an upper sandstone lithofacies (fig. 15). The contact between the two lithofacies is arbitrarily taken at the base of the first exposed bed in which the quartz fraction exceeds 50 percent and is in framework support. The overall lithologic transition observed in the exposed Kibbey reflects a gradual increase in calcite and quartz content, and grain size, at the expense of dolomite, which decreases proportionately.

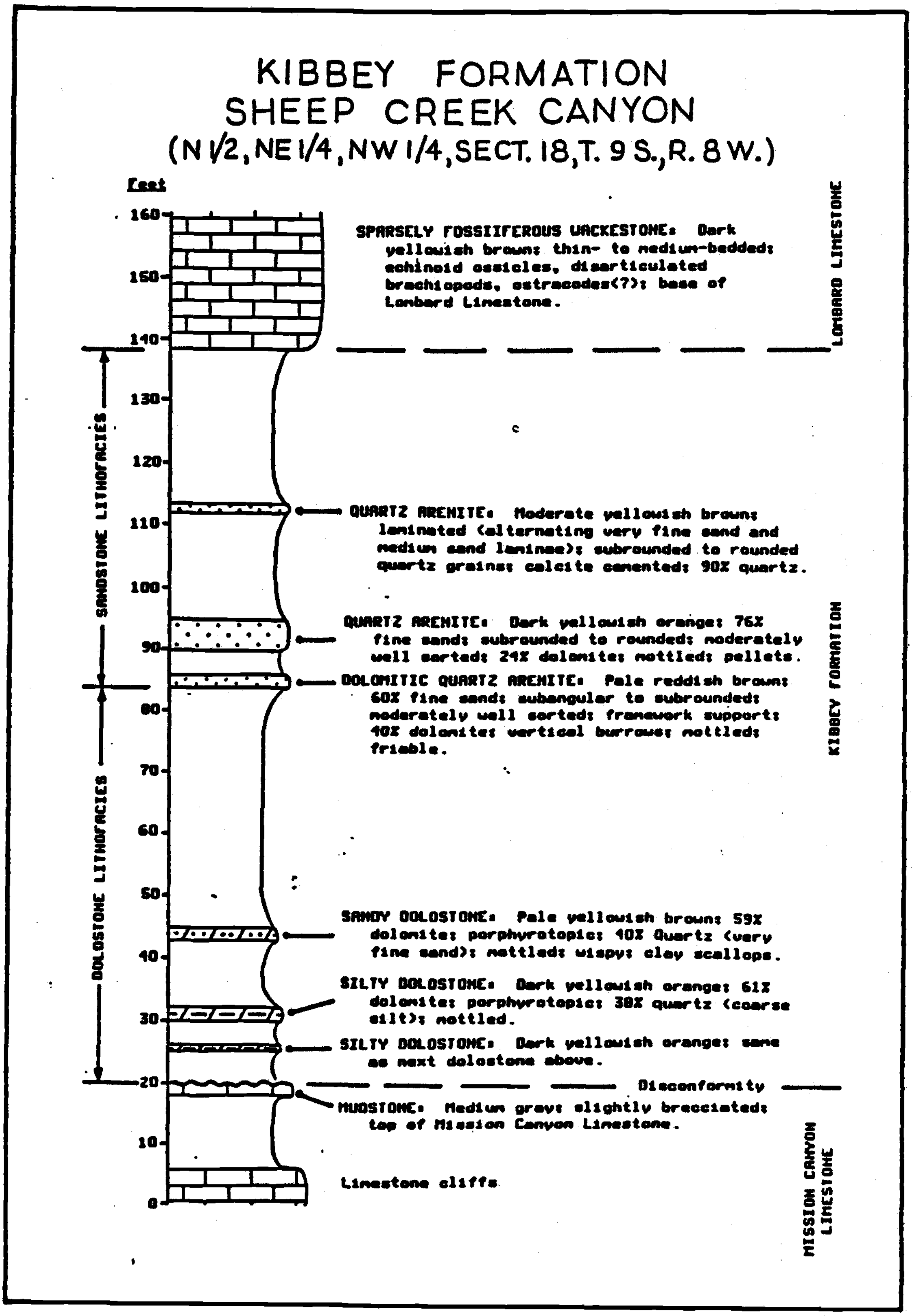


Figure 15. Kibbey Formation section in Blacktail Mountains. Blank intervals represent cover.

<u>Dolostone lithofacies.</u> The dolostone lithofacies is best exposed in the lower 25 feet of the unit, and consists of laterally discontinuous, poorly exposed silty to sandy dolostone beds, which display a crude, thin- to predominantly medium-bedded habit. Trenching reveals a very non-resistant, chippy, limy siltstone and mudstone (Williams, Turner, and Gilbert, 1982) lithology between the poorly exposed dolostone beds. The upper 35 feet of this unit are covered by a grayish orange (10 YR 7/4) to yellowish orange (10 YR 7/2) soil with very fine to fine, silty dolostone and subordinate limy to dolomitic, quartz sandstone float. The lowest exposed bed crops out five feet above the uppermost Mission Canyon ledge. As discussed earlier, the uppermost Mission Canyon paleosurface is irregular as a result of subaerial exposure and karst formation in Meramecian time.

Quartz is the sole framework constituent, but makes up no more than 40 percent of the total constituents. Grain size variations are minor, but a crude, coarsening upward habit is present in the exposed lower half of the unit. The quartz in the lowest bed is predominantly subangular coarse silt, which passes upward into subangular to subrounded very fine sand in the overlying beds. Sorting is moderate and sphericity is extremely variable. Most of the quartz grains are monocrystalline, although polycrystalline quartz and chert occur rarely.

Finely crystalline, anhedral to subhedral dolomite composes at least 60 percent of the dolostone, completely surrounding and locally partially replacing the "floating" quartz grains. Subhedral and rare euhedral dolomite porphyrotopes are scattered throughout the fine matrix, locally attaining coarse silt sizes. No evidence of rounding, which would suggest a detrital origin for these coarser dolomite rhombs, is recognized in thin section. X-ray diffraction reveals that the dolomite is slightly to moderately ferroan, and that calcite is in absentia or present in amounts too low to be detected.

Variably rounded magnetite, zircon, tourmaline, epidote, and green hornblende grains make up less than one precent of the total constituents. Both the magnetite and hornblende are altering to hematite. Indeterminate clay is also admixed within the dolomitic matrix, but composes only a minor part of the matrix.

Depositional textures have been obliterated by dolomitization of the original calcarenites. Mottling is ubiquitous throughout the exposed beds, but small clay scallops and wisps, approximately one-quarter inch long, are very common to the uppermost exposed bed. Petrographic examination reveals that these scallops and wisps consist chiefly of indeterminate hematite-stained clay, insoluble residues, and rare micrite and quartz silt grains. Pore fluid migration may partially account for these features, but the small size and random concavity, with respect to stratigraphic-up, suggest an origin resulting from bioturbation. The mottling is characterized by irregular patches with a greater concentration of dolomite, clay, and iron-oxides alternating with patches having a lower dolomite to quartz ratio (approximately 3:2 or 3:1, versus 10:1 or 12:1 in the adjacent mottles) and slightly less clay.

No fossils or fossil fragments are present in the dolostone lithofacies. Fossils are very rare in the Kibbey Formation throughout Montana, and specimens of meaningful biostratigraphic utility have not been reported to date.

<u>Sandstone lithofacies.</u> Approximately half-way upsection in the Kibbey a second set of extremely subdued ledges crops out, separated by covered intervals of variable thickness (fig. 15). The top of the unit is marked by a sharp, laterally continuous contact at the base of a thick sequence of thin- to thick-bedded, sparsely fossiliferous to fossiliferous wackestones. The uppermost 24 feet of this lithofacies are covered. All of the covered intervals in this unit, however, are characterized by a grayish orange (10 YR 7/4) to moderate yellowish brown (10 YR 5/4) soil. Limy to dolomitic siltstone and fine grained sandstone float occur locally, but the rocks underlying the covered intervals are non-resistant and, therefore, unknown; the silty to sandy soil cover suggests the presence of poorly cemented siltstone or possibly very fine- to fine- grained sandstone.

In outcrop the beds are predominantly massive and friable. Where bedding can be discerned, most is thin-bedded and planar. The uppermost exposed bed, in contrast, is very thinly bedded to laminated, displaying parting along slightly undulatory bedding planes. Grading is not recognized in any of the exposed beds of this lithofacies. As in the underlying lithofacies, fossils are absent in outcrop, although small vertical burrows, at least one inch long occur locally.

The basal bed is very similar to the underlying dolostone lithofacies, but contains appreciably more quartz. The quartz content in the exposed part of the sandstone lithofacies increases rapidly upsection, from 60 percent at the base to 90 percent in the uppermost exposed bed. Conversely, the amount of fine, mosaic dolomite, of subhedral to rarely euhedral dolomite rhombs, and of cryptocrystalline clay in the matrix decrease, passing upward into drusy calcite and subordinate dolomite.

Mean grain size of the subangular to predominantly subrounded to rounded quartz grains is moderately variable, ranging from coarse silt to medium sand. Syntaxial overgrowths are common to the quartz grains, which average 0.19 mm in diameter (fine sand). A few of the rounded framework grains are obscured by a dense, dusty alteration product which is probably kaolinite, suggesting that the detrital grains may be orthoclase or plagioclase; the absence of sericite argues for an orthoclase origin.

Dolomitized pelloids and echinoid fragments compose five to six percent of the total constituents. Most of the pelloids are slightly elliptical, averaging 0.1 mm in diameter, and all display a thin, brown, micritic envelope or peripheral film. Relatively coarse, centrifugally radiating pseudomorphic dolomite overgrowths partially to completely surround the pelloids, terminating abruptly against the framework elements and/or adjacent overgrowths, but developing a sawtooth termination where surrounded by the dirty, finely mosaic matrix dolomite.

Where the pelloids are in direct contact with the quartz framework grains they are typically deformed or squashed. A few of these structures appear to be collapsed ooliths, as the micritic rim is broken and locally overlaping. Syntaxial overgrowths are missing on these elements. Internal structures characteristic of ooliths are missing, but may have been destroyed by boring and complete micritization, and/or subsequent dolomitization. Conversely, these may have been rounded bioclasts with a thin, hardened micritic envelope which broke during deposition or subsequent compaction.

Many of the larger, well rounded elements, averaging 0.2 mm in diameter, are limpid to only slightly drusy, and more coarsely crystalline, in contrast to the dirtier, cryptocrystalline pelloids. Optically continuous, limpid overgrowths are the rule on these variably rounded grains. Many have a faint to pronounced, but thin, micritic or iron(?)-stained rim between the bioclast and overgrowth, which defines the rounded shape (fig. 16). The replacement dolomite displays unit extinction, which suggest replacement of an overgrown monocrystalline calcite element, such as an echinoid plate. The absence of a lumen structure does not preclude the possibility that some of these fragments are ossicles, but does indicate that they were either broken and reworked (abraded) prior to deposition or are entirely plates or plate fragments.

The matrix is almost exclusively dolomitic in the lower beds, although microspar occurs in trace amounts, primarily as a rare cementing agent. A porphyrotopic texture, of very fine sand size, subhedral dolomite rhombs "floating" in a matrix of medium to coarse silt size, subhedral to euhedral rhombs and/or mosaic dolomite, is very common. Cryptocrystalline material, which is yellowish to orangish brown under plane polarized light, locally

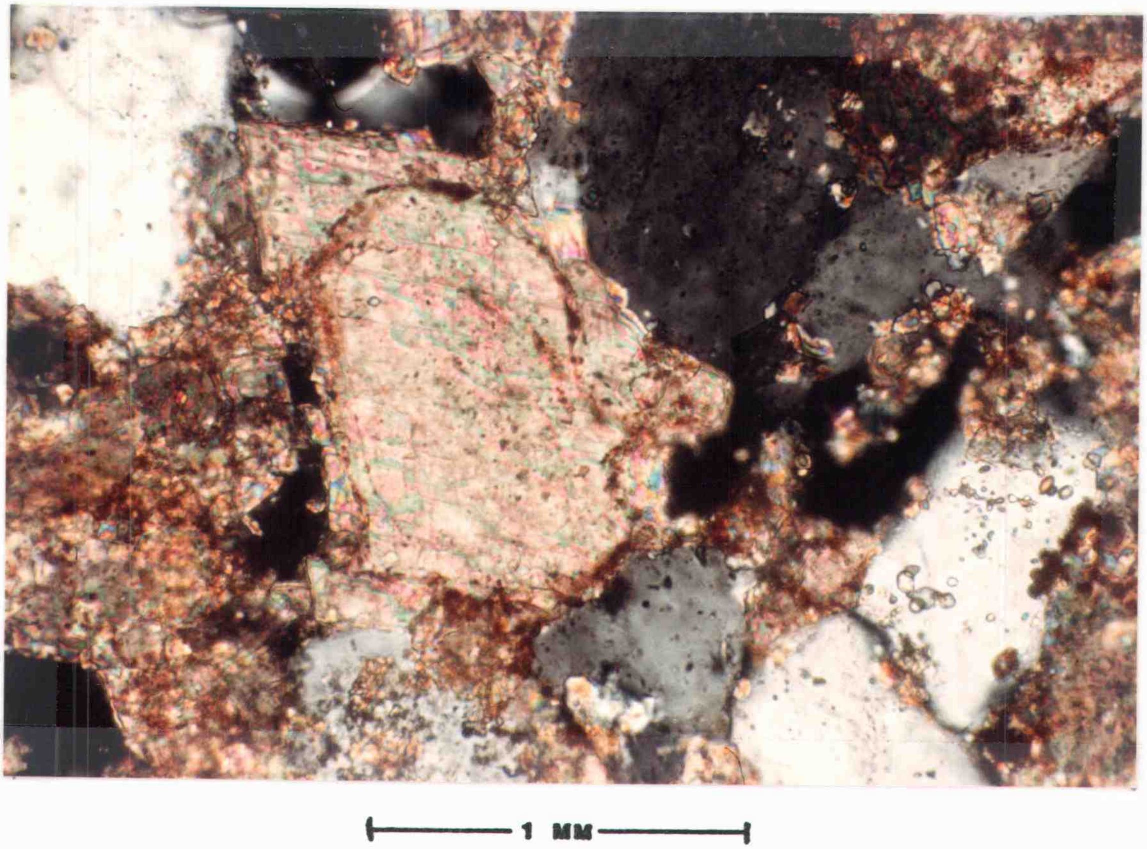


Figure 16. Dolomitized bioclast (echinoid plate or ossicle fragment?) in dolomitic quartz arenite. Note thin iron(?) stain which defines the original shape of the abraded monocrystalline bioclast. Euhedral overgrowth is in optical continuity with bioclast. Kibbey Formation, unit 9, Sheep Creek Canyon section. Crossed nicols.

surrounds or occurs between the matrix dolomite. The pseudoisotropic character under crossed nicols and very low relief suggest that this is clay. Small, intergranular pockets of this material locally make up approximately five percent of the rock.

A crude laminated habit occurs locally in the lower part of the unit. The uppermost exposed bed, in contrast, is characterized by a laminated habit and rare dolomite (fig. 17). The dolomite occurs locally as small, well developed rhombs in the drusy microspar matrix and along the corroded margins of a few quartz grains. Monocrystalline quartz composes 83 percent of the rock, but chert is much more common than in the underlying beds, making up eight percent of the total constituents. Syntaxial quartz overgrowths are common, although many have been partially replaced or corroded by relatively limpid, low-magnesium calcite cement.

Alternating, well sorted layers of subangular, very fine quartz sand and subrounded, medium quartz sand make up the millimeters-thick laminations observed in outcrop (fig. 17). Laminae thicknesses involving the coarser grained laminae display much more variability than the finer-grained laminae, which are thinner overall. Many of the quartz grains in the finer grained laminae have low sphericity values and display a crude to fair mutual orientation subparallel to bedding. Intergranular porosity is minimal, only one percent, and is restricted to the coarser-grained laminae. Small, irregular patches of relatively limpid poikilotopic calcite are also common in the coarser grained laminae. The engulfed quartz grains within these monocrystalline patches have

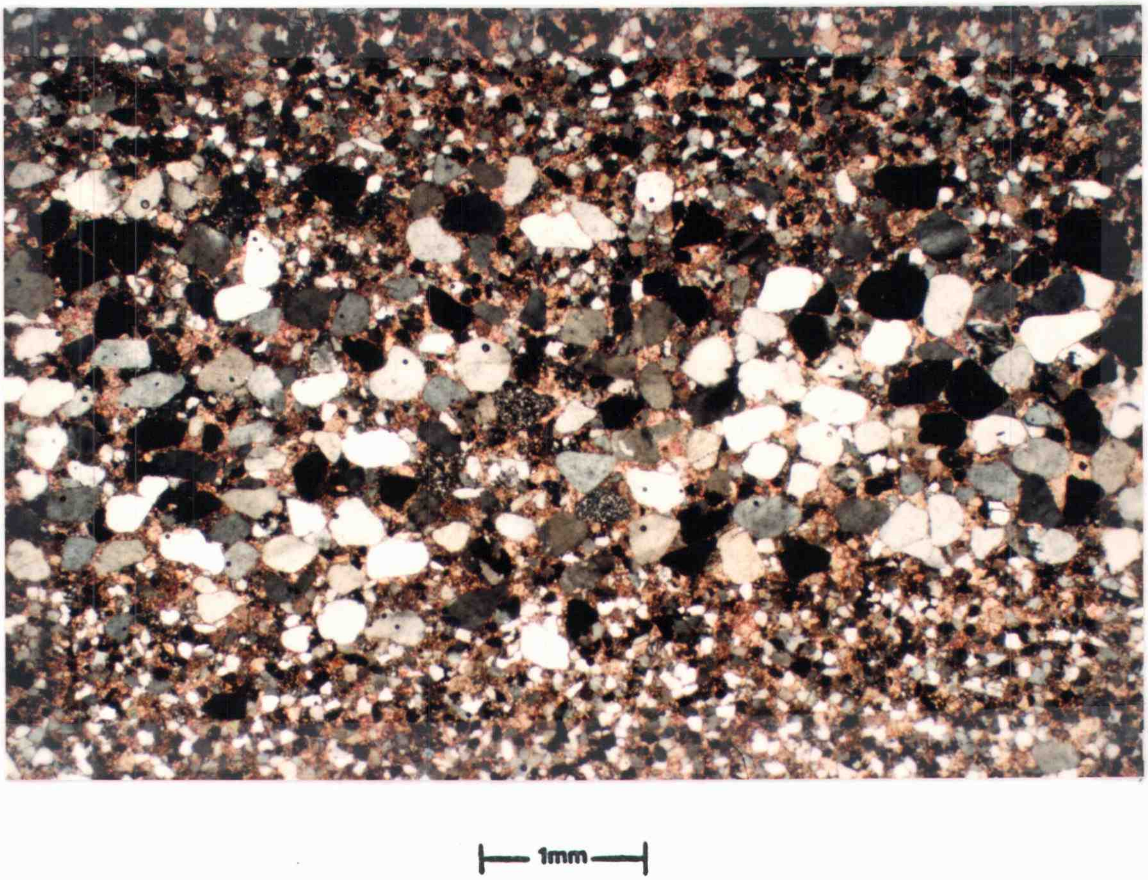


Figure 17. Plane laminated quartz arenite. See text for discussion. Kibbey Formation, unit 13, Sheep Creek Canyon section. Crossed nicols.

been pushed apart, creating a local matrix support fabric, in obvious incongruence with the pervasive framework support fabric which characterizes this unit. Transitions between the laminae are very sharp, marked by the abrupt change in grain size previously mentioned.

A common suite of heavy minerals occurs throughout the sandstone lithofacies. Magnetite and zircon are most abundant, locally composing one percent of the rock. Tourmaline is present in trace amounts. Many of the magnetite grains have partially altered to hematite, providing much of the iron for the locally intense hematite and limonite stain seen in the lower part of this lithofacies.

Depositional environment

Introduction

Kibbey sedimentation reflects initial eastward transgression of the Big Snowy sea into the Snowcrest and Big Snowy troughs following complete withdrawl of the Madison sea from the area during early late to late middle Meramecian time. Despite the poor exposure of the Kibbey in the thesis area, several general conclusions can be drawn which point to deposition on a broad tidal flat along the advancing edge of a shallow epeiric sea. Comparison of the Kibbey at Sheep Creek Canyon with Kibbey sections described elswhere in southwestern Montana support this explanation.

The most obvious trend recognized in the Kibbey at Sheep

Creek is that of a coarsening upward sequence associated with a transition from dolomite-dominated to non-dolomitic, clastic-rich lithologies (fig. 15). As water depth of the encroaching sea increased, the Sheep Creek Canyon region passed from a muddy upper intertidal area to a sandy lower intertidal area, ultimately becoming completely submerged and changing from a clastics-dominated system back to a carbonate-dominated system (plate 2).

Recent studies of modern tidal flats in a variety of climatic settings have established several criteria for the recognition of ancient tidal flats in the rock record. Modern tidal flats can be divided into three distinct environments: subtidal, intertidal, and supratidal. Recognition of all three environments is not always possible in the ancient record, however, because of multiple changes in sea level which remove or rework part of the record, and because of the inherent similarities between the depositional fabric of intertidal and supratidal environments. Tidal flats commonly develop along coastlines characterized by moderate to high tidal rhythms, but with low wave activity, in protected embayments as estuaries, along epicontinental seas, or behind protective barriers (Reineck and Singh, 1980; Shinn, 1985). Algal laminations, desiccation cracks, vuggy or birdseye porosity, low faunal diversity and abundance, early dolomite, and a landward to seaward sediment distribution pattern, respectively, of mudflats, mixed flats, and sand flats all characterize the tidal flat environment (Laporte, 1972; Reineck and Singh, 1980).

Dolostone lithofacies

The mottled, silty to sandy dolostones in the lower Kibbey represent deposition on an upper intertidal to lower supratidal environment. Rocks of the intertidal environment are typically difficult to distinguish from supratidal rocks; however, a few discrete differences can be utilized to differentiate the two. Algal laminations, desiccation cracks, fenestral porosity, and evaporites (or their pseudomorphic remnants) are considered as the chief criteria for recognition of the supratidal environment (Lucia, 1972). These features may also be found to a lesser extent in the intertidal environment, but this environment is commonly characterized by its bioturbated and burrowed fabric in the absence or near absence of algal stromatolites and evaporites. Burrowing, in contrast, is rare in the supratidal environment. Both environments are characterized by light colored sediments lacking a strong odor of decomposing organic matter (Shinn et al., 1969).

The Kibbey dolostones are very finely crystalline, ubiquitously mottled, light in color, and lack a petroliferous odor. Sedimentary structures indicative of deposition in a supratidal environment are missing or rare. Park (1976) and Shinn (1983) have shown, however, that sedimentary structures in uncemented sediment which are diagnostic of the supratidal environment are reduced to a mottled texture as a result of burial, compaction, and dehydration. The numerous clay scallops and dark brown to black, elongate wisps in the uppermost exposed dolostone bed may reflect such processes; the scallops and wisps consist of cryptocrystalline clays, insoluble residues, and scarce quartz silt and micrite. Algal mats characteristically consist of such fine materials, trapped between the sticky, filamentous algal strands during storm and/or spring tides which transport the fine material high onto the upper reaches of the tidal flat (Davies, 1970; Park, 1976).

Preservation of algal laminations is dependent upon several criteria, the most significant of which are commonly adversely affected in the intertidal environment. Hubbard (1972) has reported on the role modern soft-bodied worms and boring algae can play in the destruction of these organo-sedimentary structures. In addition, fluid loss during compaction can account for a 70 to 80 percent volume decrease, reducing the formerly centimeters-thick mat to a thin, often unrecognizable film of organic matter and fine siliciclastic and carbonate constituents (Park, 1976). Thus, while the wispy, scalloped texture of the upper dolostone bed may be the result of burial processes, burrowing may have also played a significant role in the partial destruction of the potential algal laminations.

Tysdal (1970) and Guthrie (1984) have both reported algal stromatolites in the lower half of the Kibbey Formation in the Ruby and Bridger Ranges, approximately 25 and 96 miles, respectively, east-northeast of Sheep Creek Canyon. Guthrie (1984) also interpreted dolostone breccias in the lower Kibbey as evidence of thin, laterally continuous evaporite deposits which developed on a sabkha. Evidence of evaporites, such as collapse breccias or anhydrite/gypsum pseudomorphs, are absent at Sheep Creek Canyon and in the Ruby Range, although these deposits may be represented by the covered intervals at either location (see plate 2).

The Snowcrest trough area is believed to have been situated at approximately 4 N latitude throughout the upper Paleozoic (Opdyke and Runcorn, 1960; Sandberg et al., 1983), which would suggest the presence of a moist, tropical environment regionally. The lower Kibbey, however, is characterized by variably thick anhydrite deposits to the east, in the Big Snowy trough, suggesting a hot, semi-arid to arid climate (Harris, 1972; Ballard, 1969). Implied low-latitude paleotrade winds from the east to northeast during Paleozoic time (Opdyke and Runcorn, 1960), subaerial exposure of a great part of the Cordilleran platform during Kibbey time, and the elevated transcontinental arch to the east could have created a slightly drier regional climate than presently exists at these latitudes.

A silty to sandy dolostone lithofacies is generally identifiable in the lower part of the Kibbey throughout the Snowcrest trough region (Plate 3). Primary and early dolomite is found on some modern tidal flats and is considered a diagnostic feature of such in ancient examples. The Kibbey dolostones consist of a very finely crystalline dolomite matrix containing several larger dolomite porphyrotopes. Porphyrotopic dolomite rhombs typically develop early in open pore spaces (Shinn, 1983); petrographic analysis indicates that the Kibbey porphyrotopes developed after dolomitization of the original mud, suggesting that both developed as syn- or early post-depositional diagenetic products. The original mud may have been pelletal, and this could account for scattered pore space in sediment which would not otherwise be expected to have much initial porosity.

Dolomite concentrations in surface and near-surface sediments at Andros Island are found to be intimately related to the position of the sediments relative to the normal high tide level (Shinn et al., 1969). Those sediments bearing the greatest amount of dolomite occur only a few inches above normal high tide level. A vertical relationship within the sediment is also noted; lithified sediment just below the unlithified sediment contains up to eighty percent dolomite, in contrast to the five to twenty percent figure reported in the latter. This relationship denotes the importance of early diagenetic dolomite formation in the upper intertidal and lower supratidal environment (Shinn et al., 1969). Seepage reflux in a semi-arid to arid environment is suggested as the predominant dolomite generating mechanism in these sediments. In contrast to the reflux theory of Adams and Rhodes (1960), which depends on increasing density of hypersaline brines to displace connate waters in the slightly permeable carbonates, studies of Holocene sabkhas suggest that the increased head associated with elevation of water on the supratidal flats during storms drives the reflux system (Land, 1982). Because of the absence of evidence of evaporite deposition on the upper tidal flat area the storm recharge-generated reflux model is favored in the thesis area. Alternatively, a meteoric mixing model may be employed, as this dolomitization process will operate in the absence of evaporites (Land, 1982). More time is required for this process, however, which conflicts with the early diagenetic formation of the Kibbey dolomite suggested by the porphyrotopic microfabric.

Many modern carbonate tidal flats are composed predominantly of fecal pellets and subordinate gastropods, foraminifera, or ostracodes (Lucia, 1972). Much of the diagnostic morphology of the pellets is lost during compaction into bedding units (Howard and Reineck, 1972). As dolomitization increases in these pelleted muds the pellets become progressively obscured, the dolomite crystals ultimately replacing the pellets and acquiring a mosaic texture (Shinn et al., 1969). The high percentage of finely crystalline, mosaic dolomite with scattered porphyrotopes in the Kibbey dolostones, therefore, provides additional evidence of deposition at or near normal high tide level in an upper intertidal or lower supratidal mudflat environment.

The absence of fossils additionally indicates deposition in a stressed environment inhibitory to establishment and proliferation of a shelly fauna. These dolostones cannot be confused, therefore, with subtidal dolomites, which typically display some degree of preserved fossil material (Laporte, 1972).

Finally, quartz silt and sand make up an appreciable amount of the Kibbey dolostones. This is not surprising, however, as sand and silt are commonly found in mud flat sediments (Weimer, 1982). Most of this clastic material is transported via tidal channels onto the muddy, upper intertidal area from the adjacent marine environment, lower shoreface, or sand flats by spring and/or storm tides (Bathurst, 1975). In addition, some of the terrigenous constituent found in modern carbonate tidal flats is wind-blown from nearby dunes or coastal spits (Purser and Seibold, 1973). An aeolian source may explain the variable sizes of the detrital material found throughout the dolostones, although burrowing organisms and/or storm activity are also probably responsible for some of the observed mixing of grain sizes.

A case example illustrating the problems involved with distinguishing intertidal rocks from supratidal rocks is found in the upper part of the Permian Clarkfork Formation in west-central Texas. These dolomites contain wispy to very poorly defined, irregular laminations, a few desiccation cracks, discrete quartz silt-rich beds, and a scarce fossil assemblage The mottled dolomite is made up of a finely crystalline ((5 microns) matrix with larger dolomite rhombs in the larger pores. The underlying intertidal rocks are thin to absent and display ubiquitous mottling in addition to most of the characteristic elements of the supratidal rocks; recognition of two separate lithofacies reflective of different depositional environments, therefore, is also very difficult in this analog (Lucia, 1972).

Recent work by Sando and others (1985) has documented the occurrence of a conformably intervening carbonate unit between the Mission Canyon Limestone and Kibbey Formation in the Tendoy Mountains. Lithologic features and paleontologic data indicate that this unit, named the McKenzie Canyon Limestone, represents intertidal and supratidal deposition at the westernmost edge of the broad, post-Mission Canyon karst plain (fig.9). The dolomitic unit recognized in the lower part of the Kibbey of the study area and elsewhere in southwestern Montana, therefore, may be correlative with the McKenzie Canyon to the west.

In conclusion, local textural and mineralogical characteristics, regional correlation with other Kibbey sections (Plate 3), and stratigraphic position directly above a disconformity representative of pre-Kibbey subaerial exposure suggest that the dolostone lithofacies was deposited on a muddy, pelleted(?) upper intertidal to lower supratidal environment, peripheral to or within an esturine complex at the landward edge of the advancing Big Snowy sea.

Sandstone lithofacies

In contrast to the muddy character of the dolostone lithofacies, the overlying sandstone lithofacies reflects deposition closer to normal low tide level in a sand- and silt-dominated environment. Sand flats occur closest to the low tide line and, therefore, are subjected for the longest time to the strongest wave and current energy. Small scale current and wave ripple laminations are common, as are megaripples, and flaser and wavy beds, although bioturbation and burrowing commonly destroy the laminations and homogenize the sediment (Weimer et al., 1982; Shinn, 1983). Generally, bioturbation progressively decreases in overall significance with increased sand content, related to a more seaward aspect across the flat. Upsection, these changes in sand content and associated sedimentary textures are also observed in the sandstone lithofacies, reflecting gradual transgression of the Big Snowy sea and progressively seaward deposition in an esturine lithotope.

The lowest exposed bed belonging to the sandstone lithofacies probably reflects deposition in the mixed flat environment. This environment is characterized by a variable admixture of bioturbated mud, silt, and sand (Reineck and Singh, 1980). In contrast to the underlying dolostone lithofacies, this lowermost sandstone bed contains more silt and sand than mud (dolomite), but contains more dolomite (mud) than the overlying sandstones. Vertical burrows are common, suggesting a slightly stressed environment, yet the mottled texture indicates an abundance of burrowing organisms, ruling out deposition in supratidal conditions. Dolomitized peloids and slightly to moderately abraded pelmatozoan debris indicate episodic flooding during storms which transported some subtidal elements onto the mixed flat. The slightly coarser and more rhombic dolomite matrix, lacking the porphyrotopic dolomite rhombs found in the upper intertidal environment, also suggests deposition below normal high tide level. The textural and compositional maturity of the upper exposed sandstones is evidenced by the nearly monomineralic, subrounded to rounded framework assemblage lacking appreciable clay or mud, and displaying relatively high sphericity values.

The sandstones become sandier upsection and ultimately display preservation of primary depositional structures. The uppermost exposed sandstone is characterized by thin, slightly undulatory laminations, in contrast to the mottled, unstructured sandstones exposed twenty feet lower in the section (fig. 15). Small scale current and wave ripple laminations characterize some sand flat deposits, as previously mentioned, although horizontal laminations and massive (bioturbated) fabrics are also commonly reported (Reineck, 1972; Weimer et al., 1982). Plane laminated sands, however, can occur in many depositional subenvironments within a paralic setting, limiting the precision with which a depositional environment can be determined given the minimal exposure of the Kibbey in southwesternmost Montana. Plane laminated sands, for instance, characterize the intertidal foreshore beach, upper shoreface, and upper offshore (2 - 5m water depth) zones at Sapelo Island, Georgia, although the upper offshore zone also displays variable degrees of bioturbation. In all of these zones wave energy is sufficiently strong to constantly rework the sand, destroying most, if not all, biogenic structures. Conversely, the offshore zone contains a high density of burrowing species and individuals which almost continuously rework the sediment, resulting in interbedded plane laminated and bioturbated sands (Howard and Reineck, 1972; Wunderlich, 1972). Lower intertidal sand flats (foreshore region of Howard and Reineck, 1972) likewise contain many soft-bodied burrowing organisms which destroy depositional textures. The absence of bioturbation, lack of fossils, and preservation of planar laminations in the uppermost exposed Kibbey sandstone can, therefore, be taken to suggest deposition in an intertidal foreshore beach (lower sand flat) to possibly a lower shoreface environment, where physical reworking of the sediments by wave and tidal energy exceeded biogenic reworking.

The source of sand during Kibbey deposition is uncertain, but was probably derived from the elevated transcontinental arch to the east, the Canadian shield to the northeast, and/or some unrecognized, elevated area to the north (fig. 6). During initial Kibbey deposition much of Montana was subaerially exposed as lowland plains (Sando, 1976; Roberts, 1979). Thus, a some of the sand may have come from solution and erosion of exposed upper Mission Canyon siltstones and silty limestones. Brewster (1984) has noted that streams and rivers draining the area north of the Snowcrest trough during early Kibbey time were silt- and sand-deficient. In contrast, tidal channels farther east, in the Bridger Range, contain much more sand (Guthrie, 1984). A major part of the available sand, therefore, probably was transported westward through the Big Snowy trough into the Snowcrest trough. Harris (1972) has also noted that the interrupted sandstone beds of the upper Kibbey in the Big Snowy trough reflect the episodic derivation of sand from the craton during late Kibbey time; this episodic sand supply may account for the notable paucity of sandstone beds and poor outcrop habit of the upper Kibbey in the thesis area.

The yellow to red color of the sandstones and associated sandy to silty soil is imparted by the abundant hematite in the matrix of the rocks. A diagenetic origin for the hematite seems to be the most tenable explanation for its occurrence as it only locally stains the rare matrix clays, but completely surrounds and obscures the detrital iron-oxide minerals (i.e. magnetite).

The common mottled texture, predominantly fine sand-sized quartz grains, and absence of ripple laminae in the Kibbey sandstones in the thesis area and throughout southwestern Montana may indicate lower than usual wave energy along the shoreline. A carbonate bank complex (Scott Peak Formation) began to develop and upbuild on the outer cratonic platform coincident with initiation of Kibbey deposition (Stamm, 1984). This bank complex confined clastic sedimentation to the Snowcrest trough, restricting transport west into the miogeosyncline (Sando, 1976). With continued upbuilding and/or slight tectonic elevation of the outer platform the bank may have partially attenuated some of the eastward-directed tidal and wave energy.

The Snowcrest trough was relatively narrow, probably having dimensions similar to the Red Sea or Gulf of California (plate 2), so wind-generated waves associated with the fetch of the trough were probably relatively small. Additionally, the shallow character of the basin and great distance to the thesis area, approximately 100 miles landward of the inferred hinge line (shelf margin III-1,2 of Sando, 1976), would also act to dissipate or reduce wave and tidal energy prior to arrival at the sand flats (Shaw, 1964; Irwin, 1965). Finally, an easterly to northeasterly paleotrade wind could substantially diminish the potential energy of waves moving eastward (landward) by blowing the tops off the waves, destabilizing them and promoting premature collapse prior to arrival at the shoreline (T. J. DeVries, personal communication, 1985). It is very possible that, with the exception of storm and spring tides, the breaker and surf zone was characterized by small swells, accompanied by small breaking waves.

Sufficient wave energy must have been present, however, to transport sand-sized quartz grains and winnow out much of the mud to medium silt-sized fraction. Most modern beaches consist chiefly of a medium sand-sized and/or coarser grain fraction as a result of winnowing of the finer material by high wave energy. The predominance of fine sand in the sandstone lithofacies, therefore, seems to suggest either a slightly less energetic shoreline regime, or the absence of a coarser sand supply to this part of the basin, or a combination of the two.

The decreasing dolomite content and progressive increase in calcareous cement and matrix is also instructive. Normal tidal flooding of the sand flat must have been frequent enough to inhibit dilution of the seawater by meteoric freshwater which could ultimately generate dolomite. Flooding on the mixed flat was less frequent, however, accounting for the slow replacement of the pelletal mud with dolomite. The rare dolomite in the uppermost, laminated sandstone may have been transported from the upper intertidal or supratidal areas by strong, episodic winds, or developed as a late early to late diagenetic precipitate.

The thin sandstone sequence exposed at Sawtooth Mountain can be correlated tentatively to the uppermost exposed sandstone bed at Sheep Creek Canyon, or is, at least, correlative to the middle to upper part of the sandstone lithofacies here. The non-dolomitic, mottled to laminated, quartz arenite lithology at Sawtooth Mountain is very similar to the uppermost exposed sandstone bed at Sheep Creek Canyon. Additionally, the upper part of the Kibbey Formation throughout southwestern Montana consists predominantly of sandstones with subordinate dolostones, in contrast to the lower, dolostone-rich, sandstone-deficient sequence. The sandstones exposed at Sawtooth Mountain crop out approximately 34 feet below the lowest Lombard outcrop, equating to a position well within the upper part of the Kibbey, which generally includes at least the upper 60 feet of the formation (Plate 3). Thus, both lithological affinity and stratigraphic position suggest that the Kibbey exposed at Sawtooth Mountain is correlative with the sandstone lithofacies at Sheep Creek Canyon.

In contrast, however, the Kibbey sandstone at Sawtooth Mountain is generally finer grained and contains more interstitial clay. Deposition of these sands and silts may have occurred in quieter water, slightly seaward of the sand flat in a shallow, innermost shelf to lowermost shoreface environment. The finer grain size may also reflect deposition higher on the tidal flat in the mixed flat zone, but the noteworthy absence of intergranular calcite or dolomite diminishes the viability of this option. Kulm and others (1975) have noted a similar fining seaward relationship of terrigenous clastic material along the modern Oregon and Washington shelf, associated with sorting and transport by longshore and tidal processes (mixing of unlithified Pleistocene shelf sands complicates this relationship, but the seaward fining trend involving modern clastics is present). Once deposited, these silty sands are quickly reworked by bottom dwellers (Kulm et al., 1975). A similar homogenization process is envisioned here, although some of the bimodal character may be the result of seaward transport of sand or silt grains by strong seaward directed breezes. Shamal winds in the modern Persian Gulf are likewise reported to frequently carry sand and silt particles competely across the gulf (Shinn, 1973). The laminated upper part of the sandstone exposed at Sawtooth Mountain may reflect a short-term period of lowering of wave base or seaward progradation of the tidal flat complex which brought the bottom sediments to a level near or above normal wave base. The absence of a recognizable littoral facies between the sand flat and lower shoreface-innermost shelf facies can be justified, in part, by the low wave energy proposed earlier and by the non-resistant character of the Kibbey Formation. This non-resistant character probably reflects the overall fine grain size of the Kibbey in southwestern Montana. Siltstones and subordinate mudstones are commonly interbedded with the sandstones east of the study area, explaining the infrequent outcrop habit there, and are probably common in this area as well (Plate 2).

Little is known of Kibbey deposition on the south side of the Snowcrest trough because of faulting and post-Lombard, pre-Amsden uplift and erosion (plate 2). In the Bridger Range area, at the northeasternmost end of the Snowcrest trough, Guthrie (1984) recognizes supratidal Kibbey deposits north and south of the range, peripheral to and transitional with intertidal deposits in the central part of the range which are coincident with the paleotrough axis. The upper Kibbey unit thins significantly to the north and south, onto the late Paleozoic Lombard arch and Wyoming platform, respectively, displaying a mirror image facies pattern on either side of the subsiding trough axis, similar to that seen in the lower Kibbey unit (Guthrie, 1984). Isopaching of the total Kibbey Formation displays appreciable thickening of the formation in the axial part of the Snowcrest trough, although the apparent thinning to the southeast is poorly constrained. Faulting has artificially thinned most of the sections along the southeastern margin of the trough, although thin, complete Kibbey sections are locally present at Baldy Mountain and the southwesternmost end of the Snowcrest Range (covered; see Plate 2). It is likely, therefore, that the Snowcrest trough was characterized by opposing tidal flat complexes which merged near the center of the trough or were separated by a shallow sea throughout its length during Kibbey deposition. Thus, Kibbey deposition in the Sawtooth Mountain area may have occurred on a northwest-facing tidal flat complex opposite a south-facing complex in the Sheep Creek Canyon area, or occurred in a very shallow, clastic-dominated sea which separated the two complexes.

Age and stratigraphic interpretation

Assignment of a precise age to the Kibbey Formation in the thesis area and elsewhere in southwestern Montana is not possible because of the near absence of any biostratigraphically useful fossils above the base of the formation. Correlation to time equivalent units deposited to the west in the south-central Idaho area, and bracketing by underlying and overlying units of known age, however, impose relatively tight age constraints on the Kibbey Formation.

As discussed previously, the uppermost Mission Canyon in the thesis area contains _Vesiculophyllum_ sp. and _Diphyphyllum_ sp., which are indicative of middle Osagean to late early Meramecian time (Sando and Bamber, 1979). West of the Snowcrest Range, in the Tendoy Mountains, Meramecian conodonts occur in the lower part of the Kibbey, and _Canadiphyllum_, _Clisiophyllum_, and _Faberophyllum_ are reported in the lower part of the Lombard Limestone (Sando et al., 1985); these corals are diagnostic of a late Meramecian (Coral Zone IV) age. A diverse, abundant coral fauna of Foraminifera Zone 12 affinity also occurs in the McKenzie Canyon Limestone which conformably overlies the Kibbey here (fig. 9). Foraminifera Zone 12/13 boundary fauna wass additionally collected 330 feet below the top of the McKenzie Canyon (Sando et al., 1985). Based on paleontological data of bracketing units, therefore, Kibbey deposition is restricted to a period beginning no earlier than middle Meramecian (Foraminifera zone 13) time and ending no later than late Meramecian (Foraminifera zone 14) time in the vicinity of the hingeline (Sando et al., 1985).

Sando (1976) recognizes a diachronous character in the Kibbey, suggesting that Kibbey deposition may have started and ended in the thesis area slightly later than is alluded to by biostratigraphic evidence in the Tendoy Mountain area to the west. Fossils recovered from the lower mudstone lithofacies of the overlying Lombard Limestone in the thesis area, unfortunately, do not provide any useful age constraints, so precise dating of the Kibbey-Lombard and transition is not possible. Corals and brachiopods in the next higher, fossiliferous wackestone/packstone lithofacies of the Lombard, however, are diagnostic of Coral Zone V (earliest to late Chesterian; W. J. Sando and J. T. Dutro, Jr., written communication, 1985). Therefore, the lower part of the Lombard must have been deposited during approximately late or latest Meramecian to early Chesterian time, restricting Kibbey deposition to late middle Meramecian to earliest late Meramecian time in the present Snowcrest Range area. In light of a diachronic model for Kibbey and Lombard deposition, these ages comply well with slightly older ages in the same units to the west.

The few mineralogical and lithological trends which can be drawn from the meager Kibbey exposures at Sheep Creek Canyon indicate easterly shifting of the strandline, as outlined previously, although minor regressive events within the overall trangression are recognized elsewhere in the Snowcrest trough (Guthrie, 1984). In the absence of a more completely exposed Kibbey section in the thesis area, such strandline fluctuations can only be supposed. The recognized trends at Sheep Creek Canyon may be fortuitous or even misleading, although correlation with other Kibbey sections suggest that the observed trends are real (Plate 3).

Construction of an isopach map of the total Kibbey Formation in southwestern Montana clearly illustrates the presence of a subsiding basin normal to the cratonic margin during Kibbey deposition (Figs. 18 and 19). Several peculiar variations in Kibbey thickness are noted at the head of the trough, although these are believed to reflect variable subsidence in this part of the trough (Guthrie, 1984). The anomalously thick Kibbey section at Bell Canyon (242 feet) may also reflect greater local subsidence, although the location of this section within the leading edge of the Overthrust belt, combined with its predominantly covered habit, suggest the possibility of unrecognized fault thickening. Alternatively, the thick section may reflect ponding of clastic material behind a slightly positive carbonate bank complex (Scott Peak Formation). Some of the observed variations throughout the trough may additionally reflect differential sedimentation rates, or the variable paleotopography which probably existed prior to and during early Kibbey deposition.

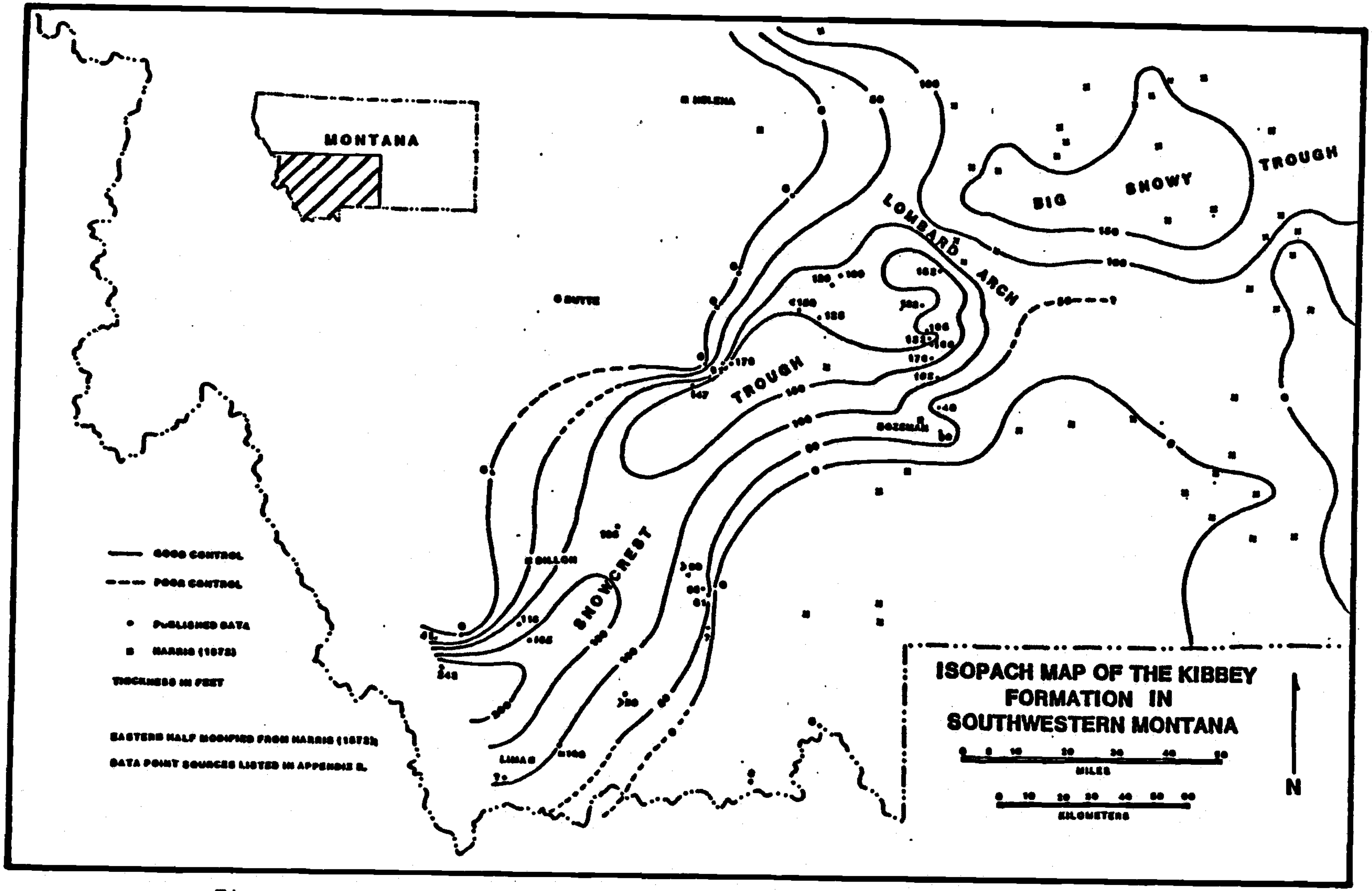


Figure 18. Isopach map of the Kibbey Formation in southwestern Montana. Contour interval is 50 feet. Figure by the author.

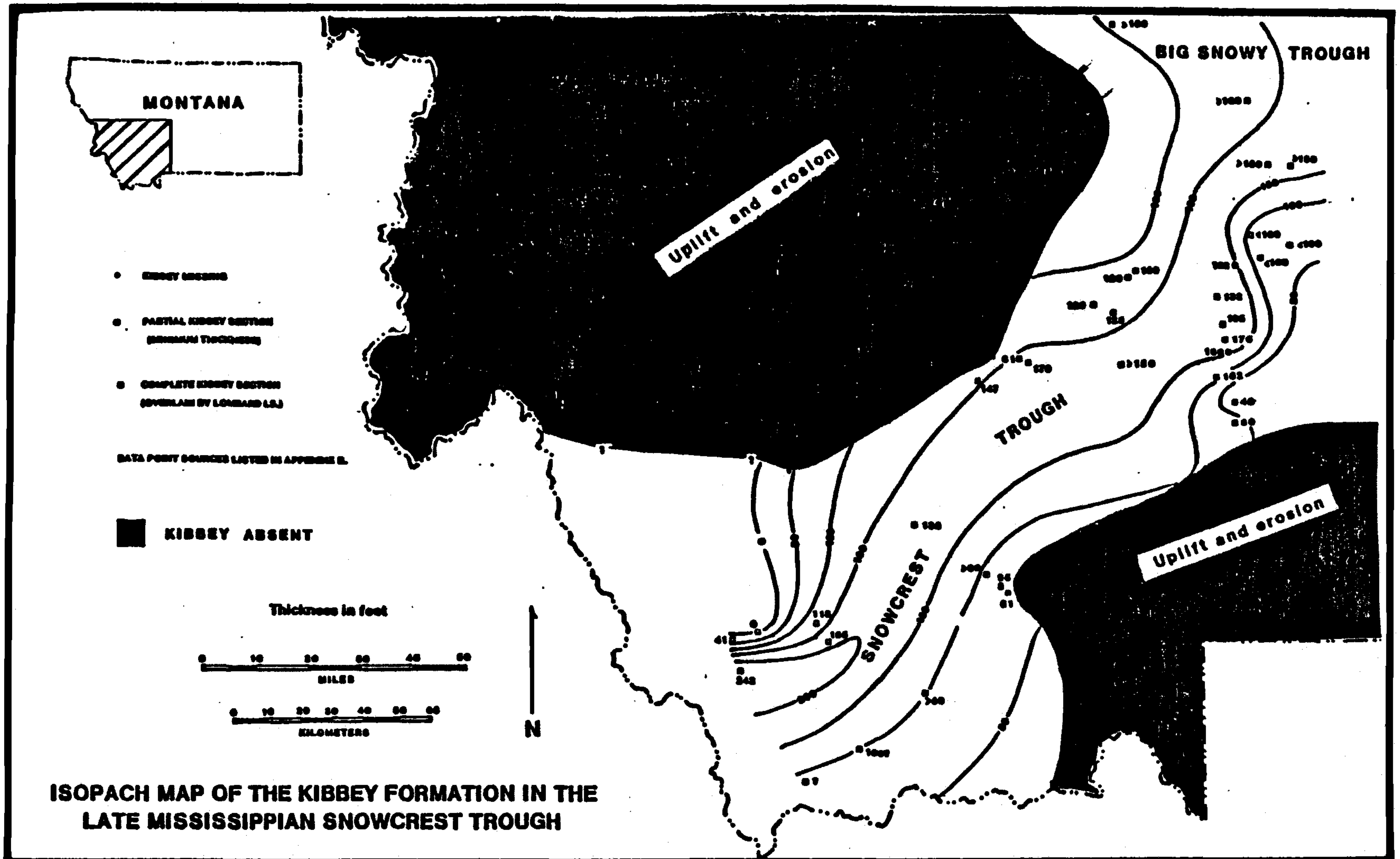


Figure 19. Isopach map of the Kibbey Formation in the Late Mississippian Snowcrest Trough. Darkened areas represent regions of post-Kibbey uplift and/or erosion. Contour interval is 50 feet. Figure by the author.

The Kibbey zero-thickness edge illustrated on Figure 18 is largely the result of pre-Amsden uplift and erosion, rather than true stratigraphic termination. The shaded regions on Figure 19, however, depict post-Kibbey, pre-Amsden, uplift and/or erosion which resulted in direct juxtaposition on either truncated Kibbey or Mission Canyon units. Thus, the remaining unshaded, isopached areas display actual Kibbey thicknesses in the part of the Snowcrest trough unaffected by pre-Amsden erosion prior to Lombard deposition. The presence of a southwest- to northeast-trending basin is still evident, although it is broader and the actual Kibbey depositional margins can only be guessed at (fig. 19).

The diachronous nature of the Big Snowy Group is well documented in the Big Snowy trough (Harris, 1972), and has also been suggested in the Snowcrest trough region (Sando et al., 1975; Sando, 1976). West of the study area the Kibbey, interpreted to be entirely of middle Meramecian age, conformably overlies the early middle Meramecian McKenzie Canyon Formation, which conformably overlies the Mission Canyon Limestone. In the thesis area, however, the Kibbey disconformably overlies the Mission Canyon, although the hiatus represented by this break is believed to be of short duration (approximately one foraminiferal zone in length; fig. 9). Farther east, at the western end of the Big Snowy trough, a similar Mission Canyon-Kibbey relationship is noted, but four or more foraminiferal zones are missing across the contact (fig. 9; Sando et al., 1975). It is apparent, therefore, that basal Kibbey deposition was time-transgressive from west to east . The notion that the increase in the length of the post-Mission Canyon, pre-Kibbey hiatus to the east is a result of progressively greater uplift and erosion in this direction can be discounted because of the presence of the Charles Formation. This uppermost Madison Group unit in the Big Snowy trough commonly directly underlies the Kibbey in the axis of the Big Snowy trough (Maughan, 1984). The variation in the length of the hiatus, therefore, reflects later initiation of Kibbey sedimentation to the east.

The diachronous character of the Kibbey is also borne out by the two informally recognized units within the formation which display basinwide distribution and maintenance of nearly constant thickness proportions from southwest to northeast (Plate 2). In the absence of a diachronic model for Kibbey sedimentation, explanation of the lower unit would necessitate time-synchronous deposition of intertidal and supratidal sediments across a tidal flat complex extending more than one hundred miles landward (fig. 19). Although the tidal range necessary to generate such deposition may not require anomalously large values, several other hydrologic parameters suggest the fallacy of such a model. For instance, assuming a hypothetically (and highly unlikely) horizontal tidal flat of the previously established dimensions, the rising water would have six hours to migrate approximately one hundred miles, requiring a flow velocity of 16 miles per hour! The ebb tide flow usually displays a greater velocity than that of the flood tide, suggesting an even greater returning flow velocity across the flat. These values characterize higher velocity river flow much more than swash zone velocities. Such velocities should generate large channels and/or megaripples and other cross-bedding structures, but none are recognized. In addition, flow velocities of this magnitude would be capable of eroding and transporting grains much larger than the silt to fine sand which characterizes the lower unit; but such are not found here (Plate 2).

Deposition of the upper unit, and the sharp transition between the lower and upper units, would require an abrupt basinwide rise in sea level (or equal basinwide subsidence) and time-synchronous shoreface deposition across an equally broad zone. This also seems unlikely. Thus, the most tenable way to account for the stratigraphic character of the Kibbey subunits is to apply a diachronic model in which simultaneous deposition in several different environments occurs throughout the trough, reflecting local water depth and/or position on the tidal flat complex. The proportional thickness ratios and sharp transition between the upper and lower units, therefore, reflects lateral (eastward) migration of the different facies coincident with the overall rise in sea level or epeirogenic downwarp during Kibbey time.

Comparison of Kibbey and Lombard thickness values in complete sections throughout the Snowcrest trough additionally suggests a diachronous character to the Kibbey-Lombard sequence as a whole (Fig. 20). In this construction, the Kibbey is observed to thicken with respect to the Lombard toward the basin margins and to the northeast, toward the mouth of the trough. In contrast, the Lombard is thickest with respect to the Kibbey in the axial part of the basin and to the southwest, toward the mouth of the trough.

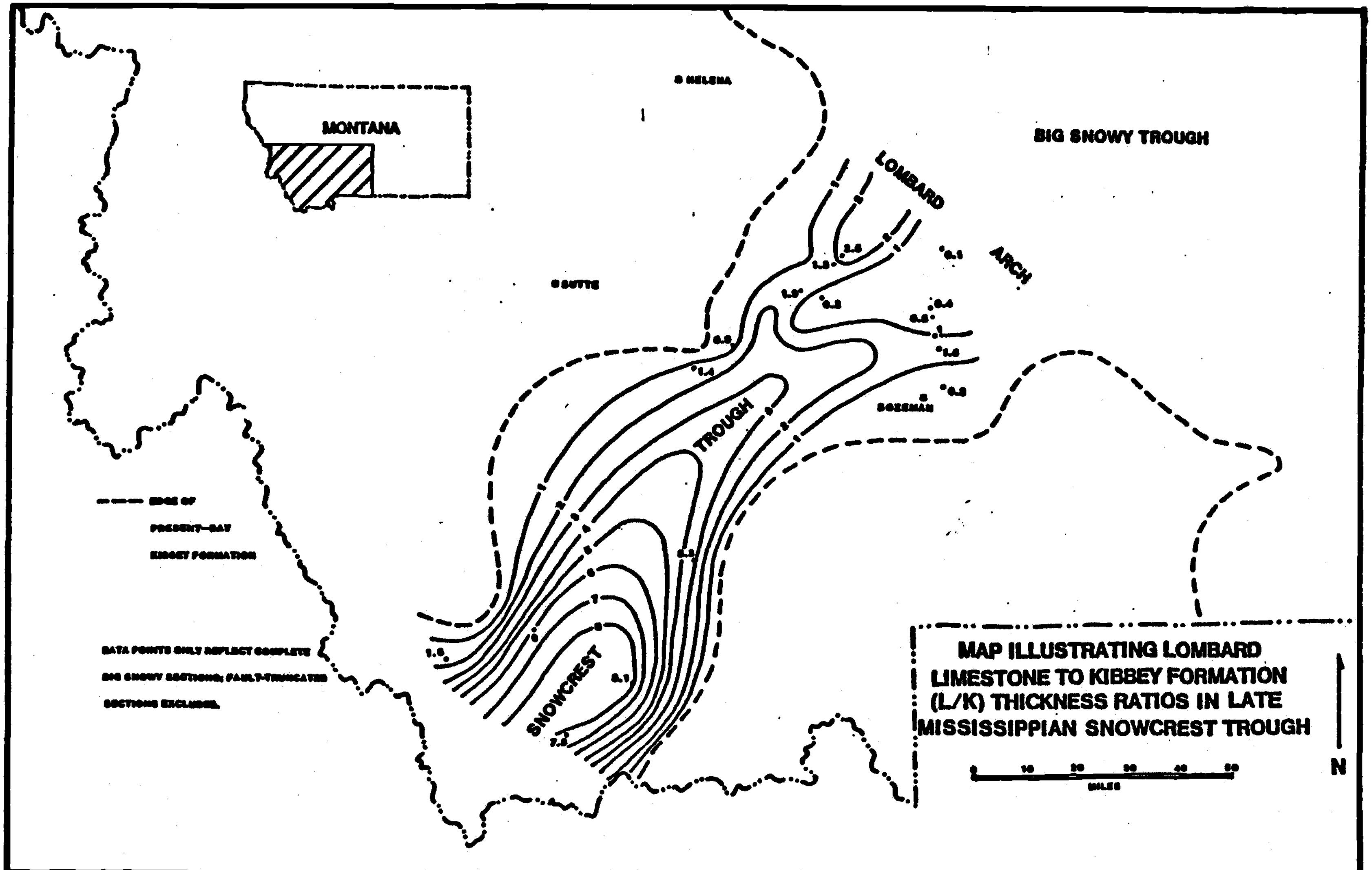


Figure 20. Map illustrating Lombard Limestone to Kibbey Formation thickness ratios in southwestern Montana. Figure by the author.

LOMBARD LIMESTONE: DESCRIPTION

Introduction

The Lombard Limestone crops out sporadically throughout the Snowcrest Range, commonly developing small hills or knolls adjacent to the major peaks of the range that are characteristically underlain by resistant Pennsylvanian and Permian age rocks (figs. 3,4). The best Lombard exposures occur at Sliderock and Snowcrest Mountains, where the Lombard crops out in steep, treacherous cliffs, associated with faulting and/or Pleistocene glaciation. The most complete section, however, is found in the Sawtooth Mountain vicinity, although thin covered intervals obscure a few important relationships. Elsewhere in the range the Lombard is variably exposed in sections having a moderate to large percentage of covered intervals which chiefly occur in the lower part of the formation.

The Kibbey-Lombard contact is typically obscured by float or soil cover, or is missing because of thrust faulting. The total thickness of the Lombard, therefore, is uncertain at most sections in the Snowcrest Range. Most Cretaceous through Tertiary thrusting in this area was localized along the transition zone between the incompetent Kibbey Formation and the competent Lombard Limestone. Only a minor amount of section, if any, is believed to be missing from the exposed basal part of the Lombard, except at Sunset Peak where back-limb thrusting has substantially shortened the Lombard section. The Lombard thicknesses in the thesis area are interpreted as minimum values, but close to the original values.

Two to four major lithofacies are recognized at most of the measured section locations. Where all four lithofacies can be discerned they include, in ascending stratigraphic order of predominant occurrence, a lime mudstone, fossiliferous wackestone-packstone, calcareous shale, and dolomitic lime mudstone lithofacies. This ascending lithofacies sequence is best illustrated at Sawtooth Mountain (plate 3).

Intertonguing of the first two lithofacies, which comprise at least 80 percent of Lombard deposition, disrupts and complicates the overall stacked lithofacies arrangement. Correlation of the lithofacies in the thesis area reveals six northeastward-thinning lime mudstone tongues which interdigitate with six southwestward-thinning fossiliferous wackestone-packstone tongues (plate 3).

The upper part of the Lombard is characterized by calcareous shale, which directly overlies the fossiliferous wackestone-packstone lithofacies throughout most of the Snowcrest Range, and a capping sequence of variably dolomitized lime mudstone. Exposure of the thinner, uppermost two lithofacies is restricted to only three locations, although covered intervals at this level combined with characteristic float suggest their presence elsewhere in the range.

Overall Lombard deposition in the thesis area reflects progradational carbonate sedimentation in response to episodic differential subsidence in the southwestern part of the Late Mississippian Snowcrest trough and/or sea level fluctuations. The fossiliferous wackestone-packstone and lime mudstone lithofacies reflect deposition in shallow, moderate to high energy environments and deeper, quiet water environments, respectively. Shallow water deposition will refer to sedimentation at, or above, normal wave base, whereas deep water deposition herein refers to sedimentation below normal wave base, within or below the photic zone.

It is important to note that the sharp lithofacies transitions suggested by the correlation lines on Plate 3 are actually gradational. The lines which define the lithofacies tongue are best approximations of the transition observed in the field, and are not taken to indicate an instantaneous change from one lithofacies to the next. Sporadic covered intervals and insufficient internal biostratigraphic control additionally preclude precise definition of the tongue dimensions, although faunal and textural dissimilarities between the two lower lithofacies permit refinement of the tongues as shown.

The lime mudstone lithofacies tongues are labelled on Plate 3 with the letter "D" to reflect deep water deposition as previously defined. Those tongues representing the progradational fossiliferous wackestone-packstone lithofacies are labelled with the letter "S" to reflect shallow water deposition. For the purpose of discussion the tongues are identified from oldest to youngest by the Roman numerals I through VI, followed by the letter "D" or "S" to indicate the respective lithofacies; the same identification scheme is utilized on Plate 3.

Lime mudstone lithofacies

The lime mudstone lithofacies consists of medium- to thick-bedded, cherty limestones with thin- to medium-bedded silty limestone and silty, calcareous shale interbeds. Laterally continuous, barren to fossiliferous mudstones and sparsely fossiliferous wackestones are characteristic of the lower part of this unit everywhere in the range. At Sawtooth Mountain, where much of this lithofacies is exposed, the lowest beds appear to be almost barren in outcrop and pass upward into the common fossiliferous mudstones and sparsely fossiliferous wackestones.

As a result of the intertonguing relationship with the fossiliferous wackestone-packstone lithofacies, this lithofacies generally thickens overall to the southwest. The thickest uninterrupted section is 410 feet at Clover Divide. The adjacent sections at Red Rock River and Sawtooth Mountain are slightly thinner (315 and 355 feet thick, respectively). This major tongue branches northeastward into four separate, thinner tongues. Two additional, stratigraphically higher tongues originate farther to the southwest and only extend to the Sunset Peak area (plate 3). Sawtooth Mountain affords the most complete, accessible exposure of this interval in the southwestern half of the range; it is best exposed in the northeastern half of the range at Snowcrest Mountain.

Discontinuous to continuous ledge-forming sequences are common, interrupted laterally and vertically by covered intervals which reflect underlying less resistant limestones, silty limestones, and/or calcareous shales. In steeper sections the discontinuously exposed ledges can be traced along strike for tens to hundreds of yards with little or no variation in lithology. At localities where the slope underlain by this lithofacies is gentle, the ledges are typically very subdued and trenching is often required to establish the relationships between beds. Many of the planar to slightly undulatory mudstone and wackestone ledges display a laminated to more commonly flaggy splitting habit. Massive beds occur locally, although the aforementioned splitting habit is frequently observed in laterally equivalent ledges. The transition between the limestone ledges and less resistant silty limestone and shale interbeds is typically sharp and slightly undulatory, but a gradual transition over several inches is noted at a few outcrops.

Chert nodules are common, although the greatest number occur in the lower part of the lithofacies, in tongues ID through IVD. The grayish orange (10 YR 7/4) nodules vary from irregular to elliptical, but the majority display a well defined augen shape and attain dimensions of six inches by eight inches. Chert stringers, typically moderate yellowish brown (10 YR 5/4) to dark yellowish brown (10 YR 4/2) in color, are less common and occur chiefly in tongues IID and IIID, at Sliderock and Snowcrest Mountains (plate 3). Most of the stringers are a few inches or less in width and locally reach fifteen feet in length.

The limestones are characteristically dark, ranging from black (N1), to olive black (5 Y 2/1), to grayish black (N2) on a fresh surface. A slight lightening in fresh surface color is noted upsection at a few locations, however, becoming dark gray (N3) to medium dark gray (N4). Greater variation is seen on weathered surfaces, which vary from very pale orange (10 YR 8/2) and yellowish gray (5 Y 8/1) to the more common light gray (N7) and light olive gray (5 Y 6/1).

In the field many of the rocks of this lithofacies appear to be barren or very sparsely fossiliferous. Laminated intervals are moderately common, but are subordinate in proportion to the massive intervals. In thin section the barren appearance of these rocks is found to be a function of the fine size of the allochemical constituents. Petrographic analysis reveals that four microfacies characterize the bulk of this lithofacies, and that several other unique microfacies occur rarely. The four most common microfacies include fossilferous micrites (typically spicule- and ostracode-rich), sparse spicular biomicrites, sparse biomicrites (sponge spicules less significant to absent), and sparse to packed biopelmicrites.

Straight to broadly curved sponge spicules (monactines and diactines) and ostracodes dominate the biotic fraction throughout most of the lithofacies (fig. 21). Typically subordinate, but locally significant fossils also include calcispheres, pelecypods, brachiopods, echinoid ossicles and plates, and gastropods. Phosphatic skeletal fragments, foraminifera, and pollen spores(?) occur rarely. Bioclasts tend to compose approximately 30 percent of the total constituents, although a few beds containing up to 60 percent bioclasts also occur. The majority of the bioclasts do not exceed very fine sand size and are disarticulated or broken. Whole specimens are commonly present, especially in the lower part of the lithofacies. Evidence of abrasion is absent, suggesting that these particles were not transported far, were transported solely in suspension, or represent in situ development with minor reworking.

Micrite is the chief matrix element, although neomorphism has largely altered the micrite to microspar (<30 microns) and less commonly to psuedospar (>30 microns). Dark, organic-rich clots and threads anastomose throughout the micritic matrix, imparting much of the dark color observed in these rocks (fig. 21). Geochemical analyses indicate a total organic carbon content in these limestones ranging from 0.19 to 1.10 percent of the total rock. The high organic content of the rocks is evident in the field by the strong to very strong petroliferous odor given off when struck by a hammer, and by the oily film observed locally on fracture surfaces. Sparry calcite is very rare to absent, typically occurring only as intraparticle fill in whole fossils (fig. 21).

In general, the lower and upper parts of the thick lime mudstone interval in the major tongue of the Lombard at Red Rock River, Clover Divide, and Sawtooth Mountain are dominated by sparse biopelmicrite with subordinate laminated sparse biomicrite and fossiliferous (spicular) micrite interbeds. The biopelmicrites typically contain subequal quantities of bioclasts and peloids, the remainder of the rock being composed of organic-rich micrite. Random orientation and distribution of the biotic constituents is prevalent, although peloidal units displaying fossils aligned subparallel to bedding occur rarely. In a few places the fossils are additionally clustered into a pod-like arrangement, surrounded by less fossiliferous biopelmicrite or biomicrite.

The peloids in the biopelmicrites are typically elliptical in thin

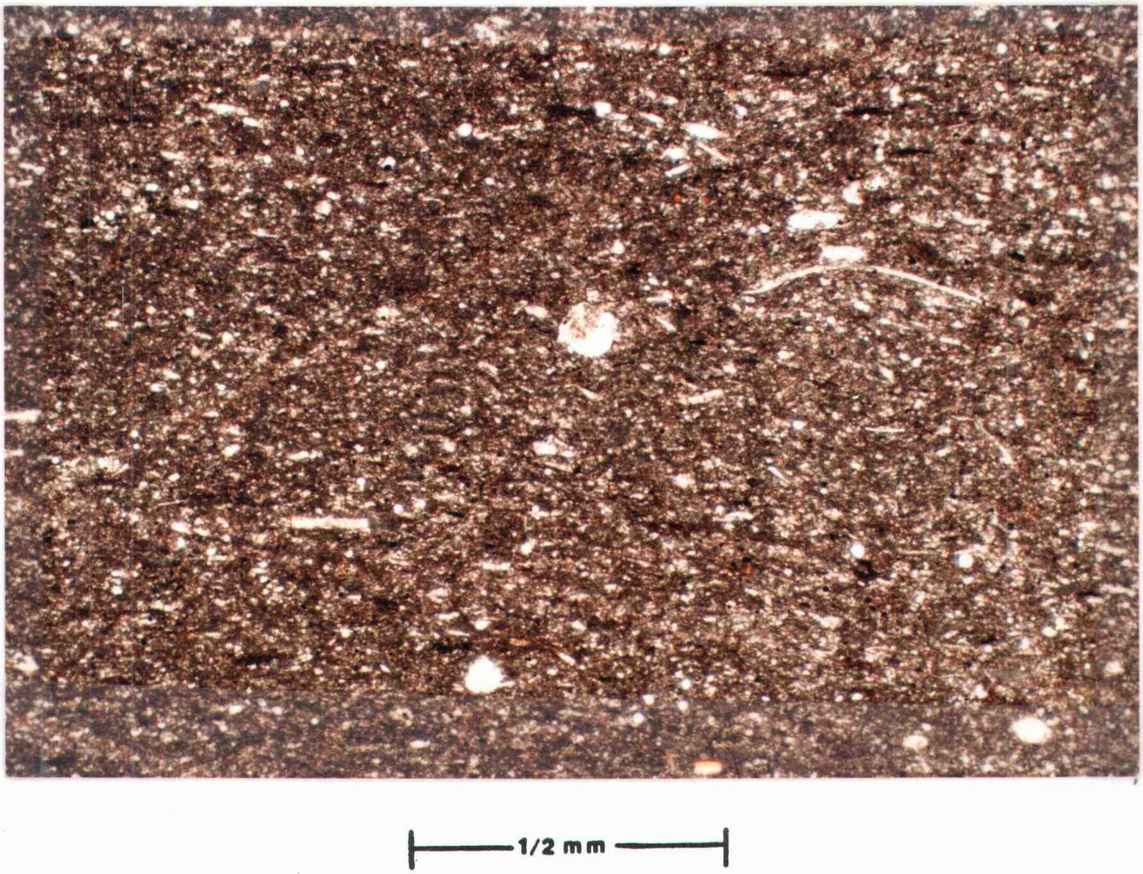


Figure 21. Typical sparse biomicrite of lime mudstone lithofacies. Note abundant sponge spicules and disarticulated ostracodes which are oriented parallel to bedding. Few articulated, sparry calcite-filled ostracodes. Unit 10, Sawtooth Mountain section. Plane polarized light.

section and average 120 microns in diameter. Much of the peloidal texture has been lost because of reworking of the sediment, or micritization and subsequent disintegration of the pellets prior to lithification, and/or diagenetic alteration, suggested by the relict pelletal texture observed in many of the biomicrites.

Sponge spicules and ostracodes comprise most of the lime mudstones as previously mentioned, although echinoid ossicles and plates, gastropods, and disarticulated bryozoan fragments occur locally. Microscopic examination reveals that many of the brachiopods have very thin valves, averaging 30 microns thick and randomly bored. Foraminifera and trilobite fragments occur rarely in the upper part of this thick interval, at a level approximately correlative to tongue IIIS or the upper part of IIID. Trace fossils, which are crescent shaped (approximately 1/2 inch in total length) and of very low relief, are found along bedding planes in the lower part of this interval at Clover Divide. These traces closely resemble <u>Helmanthopsis</u> grazing trails described by Miller and Knox (1985; p. 84, and their figure J on Plate 1).

The laminites are typically the least fossiliferous appearing rocks in outcrop. The laminae are predominantly planar and very thin (<1/16 inch) to thin (<1/8 inch), although undulatory laminae and laminae up to 1/2 thick inch occur rarely. In thin section, calcareous monactines and whole to disarticulated ostracodes are found throughout these fossiliferous micrites and sparse biomicrites, accompanied by random occurrences of many of the aforementioned biotic elements. Siliceous sponge spicules are less common. Most of the calcareous monactines probably reflect primary diagenetic replacement of siliceous spicules by mosaic, low-magnesium calcite, while the siliceous monactines may reflect secondary diagenesis of opaline sponge spicules initially altered to calcite (J. K. Rigby, personal communication, 1985). A marked size variation is noted between the two sets of spicules, however, suggesting different origins or preferential replacement.

Size sorting in the laminites is characteristically poor, although the shape fabric imparted by the bioclasts is typically excellent. Thus, the laminations observed in outcrop are discovered in thin section to be, in part, a function of the preferred orientation of the bioclasts, and also the result of subtle variations in spicular packing density, bioclast size, and organic matter content. Burrows and evidence of bioturbation are lacking in the laminated intervals, although isolated structures suggestive of burrows or cylindrical pellets, similar to those created by Pleistocene crabs, are observed in the lower part of the lithofacies at Sawtooth Mountain (T. J. DeVries, personal communication, 1985). The lowest exposed beds at Sawtooth Mountain are very finely laminated (<0.5 mm thick) and contain only a few (one percent) scattered calcareous and siliceous monactines, and disarticulated ostracode carapaces which lie parallel to the laminae.

At Clover Divide, phosphatic pellets occur in a very thin laminated interval within a bioturbated fossiliferous micrite bed near the base of the section. X-ray diffraction analysis indicates that these pellets, which attain dimensions of 6.5 mm by 3.9 mm, are fluorapatite. An authigenic origin for these pellets is suggested by their scalloped outline, although a thin film of iron oxide(?) surrounds most of the pellet and is locally missing on the rounded positive ("high") areas of the pellet edge, indicating transportation prior to deposition. The degree of rounding of the pellets appears to be, in part, a function of the pellet size, as the smaller ones commonly are well rounded and surrounded by a thin iron-oxide film, while the larger pellets display a more variable profile. The internal fabric is that of isotropic, amorphous pelloids which, unfortunately, blend together near the margins, obscuring the possible presence of truncation textures which might positively indicate a detrital origin. The well rounded habit and absence of the peripheral iron-oxide film on positive areas, however, suggests a detrital origin for these pellets. Included in this laminated interval are several moderately large, disarticulated and whole pelecypods and gastropods, suggesting deposition as a result of an episodic storm event followed by draping and infilling of the interparticle space with finely laminated micrite.

Phosphatic material is moderately common throughout the lower Lombard, although the majority is believed to represent fish debris and/or conodont fragments. At the extreme northeast end of the Snowcrest Range, however, finely disseminated phosphatic material of unknown origin occurs in the lowermost exposed spicular biomicrite bed (tongue ID).

The middle part of the major lime mudstone tongue consists primarily of sparse biomicrites, biomicrites, and less common fossiliferous micrites. With the exception of isolated laminated intervals, many of the beds in this part of the lithofacies are bioturbated and/or burrowed. Patchy or swirled micrite, accentuated by differential neomorphism is common and can frequently be recognized by the variable weathering texture in outcrop. Where bioturbation is not evident in outcrop it can nonetheless be recognized by the associated random orientation and distribution of the bioclasts, reflecting post-depositional mixing. Some of the beds lacking laminations contain a bioclast assemblage displaying alignment subparallel or parallel to bedding.

Burrows are moderately common within discrete levels throughout the middle and upper parts of the section. Correlation of these burrowed intervals from section to section is not possible. Most of the burrows are horizontal to inclined, and vary from straight to hooked. Straight, vertical burrows are found locally, but the majority of these occur in the lower part of the unit. All of the burrows observed in the field and in thin section are characteristically short and of very small diameter, suggesting construction by annelids or some other slender, soft-bodied animal (T. J. DeVries, personal communication, 1985).

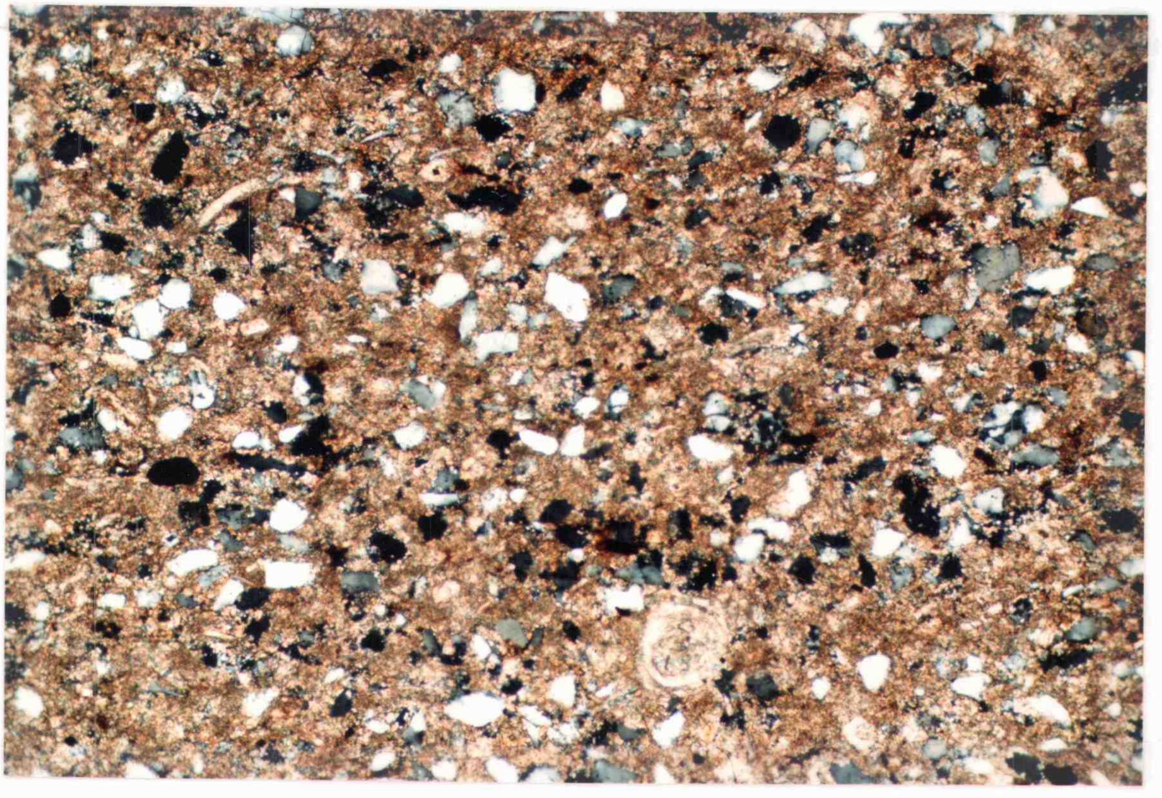
As above and below, sponge spicules and ostracodes are generally ubiquitous, although pelmatazoan and brachiopod debris becomes increasingly significant upsection. The bioclast content in the middle part of the thick interval increases from Red Rock River (averages 16 percent) to Sawtooth Mountain (averages 38 percent). Farther northeast in tongues ID, IID, IIID, and IVD the fossil content tends to remain constant or decrease slightly.

Angular quartz silt is present in most of the limestone beds of this lithofacies, although seldom in proportions exceeding three percent. Silt content in the silty limestone and shale interbeds is slightly higher, averaging ten percent. The expected decrease in quartz silt from base to top of the lithofacies is not recognized anywhere in the thesis area. In contrast, the quartz silt distribution is found to be highly variable from bed to bed. One ten foot thick fossiliferous mudstone sequence, cropping out approximately two-thirds up the major lime mudstone tongue at Red Rock River, is very silty, containing 9 to 35 percent angular to subangular quartz silt (fig. 22; units 10 to 13; see Appendix A). Despite the anomalously high clastic content of this interval ostracodes, sponge spicules, pelmatazoan fragments, broken brachiopods, and gastropods are present, although in greatly reduced numbers (three to eight percent). In accordance with the variation observed within the entire lithofacies, this silty limestone sequence is directly overlain by a fossiliferous limestone with less than one percent quartz silt.

Similar isolated, silty, fossiliferous limestone beds are found at the base and middle to upper middle parts of most of the measured sections, although the quartz content never exceeds twelve percent and is commonly below six percent. Correlation of silty and sandy intervals from southwest to northeast is not generally possible, although a few silty sections can be crudely correlated through the thesis area.

Tongue ID

Plate 3 illustrates six northeastward projecting lime mudstone tongues indicative of six major episodes of deepening of the sea in the thesis area. The basal tongue, ID, directly overlies the Kibbey



1 MM

Figure 22. Silty fossiliferous micrite in lime mudstone lithofacies. Note scarce bioclasts. Slightly crushed foraminifer in upper part of photo. Quartz is predominantly coarse silt-sized. Unit 11, Red Rock River section. Crossed nicols.

Formation and is relatively thin, never exceeding 50 feet in thickness. Sponge spicules (monactines) predominate, although whole and broken gastropods, and disarticulated echinoids are relatively common as a subordinate assemblage. Articulated and disarticulated ostracodes, disarticulated pelecypods, and conodont fragments are less common to rare.

These basal beds are generally massive, but the bioclasts are typically oriented parallel to subparallel to bedding. The larger faunal elements, however, often display a random orientation. Horizontal to inclined burrows are moderately common. Many of the burrows display slightly different infilling material suggesting multiple periods of burrowing or differential neomorphism. Some of the allochems, especially the sponge spicules, have been replaced by phosphate. Fine, faint yellowish to golden colored patches of phosphatic(?) material are additionally disseminated throughout the micritic matrix. Chert is also replacing some of the allochems.

Tongue IID

Tongue IID is similar to tongue ID, although ostracodes tend to be more abundant and scarce brachiopod, fenestrate bryozoan, and foraminiferal debris are also present. Horizontal and, less frequently, inclined burrows are abundant throughout this tongue. Many of the burrows are hooked, however, rather than straight. Echinoid debris tends to be common in the lower and northeastern part of the tongue, but is nonetheless subordinate in abundance to the sponge spicules. Most of these sparse spicular biomicrites are moderately to extensively bioturbated and poorly sorted.

Tongue IIID

The next highest lime mudstone tongue, tongue IIID, contrasts sharply with the lower two tongues. Although sponge spicules are omnipresent and succeded by echinoid, ostracode, brachiopod, and pelecypod debris, the limestones are characteristically argillaceous to silty. In addition, mosaic to fine, subhedral to euhedral dolomite rhombs compose up to ten percent of the limestone.

A 25-foot thick, laminated chert limestone sequence dominates the lower part of the tongue at Snowcrest Mountain, although this sequence was not recognized or is covered at Sliderock Mountain. This cliff-forming unit consists of four- to eight-inch thick barren(?) lime mudstones separated by one- to two-inch thick chert stringers which are laterally continuous on outcrop.

Tongue IVD

The fourth deepening event, represented by tongue IVD, was also characterized by moderate clastic input, greater overall than in any of the three previous deepening events reflected in tongues ID, IID, and IIID. In the northeastern end of the Snowcrest Range medium silt- to very fine sand-sized, angular to subangular quartz grains compose from nine to sixteen percent of the total constituents in the lower half of the tongue. As much as six percent quartz silt is also found in the southwestern end of tongue at Hogback Mountain, immediately northeast of its incorporation into the major lime mudstone tongue. Farther southwest, at Sawtooth Mountain, the uppermost sparse spicular biomicrites, correlative with this tongue, contain no more than two percent quartz.

Finely crystalline, subhedral to rarely euhedral, rhombic dolomite makes up one to ten percent of the silty lime mudstones at Snowcrest Mountain. Dolomite is absent or very rare in correlative exposed beds farther southwest. Fine pyrite masses are common at this level in several of the exposed beds northeast of Clover Divide. Much of the pyrite occurs in chambers of foraminifers or as a partial replacement product of sponge spicules, brachiopods, and ostracodes. In contrast to the paucity of gastropods in the lower lime mudstone lithofacies tongues, gastropods occur basinwide in this tongue and correlative beds to the southwest. The overall faunal diversity, however, is similar to that of the preceding lime mudstones.

Tongue VD and VID

Tongues VD and VID originate in the southwesternmost end of the thesis area and cannot be traced to the northeast beyond Sunset Peak. The faunal assemblages in both tongues are similar to those elsewhere in this lithofacies. Bioturbation is ubiquitous, but many of the elongate bioclasts display a moderate subparallelism to bedding. Burrows are less common.

Tongue VID is relatively thick at Red Rock River, but thin at Clover Divide, suggesting contrasting sedimentation and/or subsidence rates which caused the shallow to deep water facies transition zone to remain relatively fixed in position. Unrecognized faulting may also account for this thickness variation.

Fossiliferous wackestone-packstone lithofacies

The fossiliferous wackestone-packstone lithofacies is the best exposed Lombard lithofacies throughout the Snowcrest Range. In contrast to the lime mudstone lithofacies, medium- to thick-bedded fossiliferous wackestones and thin- to thick-bedded packstones, accompanied by subordinate sparsely fossiliferous wackestones, fossiliferous mudstones, and isolated grainstones characterize this lithofacies. One lenticular limestone lithoclast conglomerate occurs at the top of this lithofacies at Sawtooth Mountain. Very thin- to rarely medium-bedded silty and shaly limestone interbeds are common, although the majority are shaly and several contain moderate to very abundant brachiopod assemblages. Table 1 (at the end of this chapter) outlines the most significant features which characterize and distinguish the lime mudstone and fossiliferous wackestone-packstone lithofacies.

A parallel, planar to slightly undulatory, flaggy to slabby splitting habit is observed in many of the wackestone and packstone beds. Gradational contacts between the fossiliferous beds and silty to shaly lime mudstone interbeds are rare; most are sharp, and planar to slightly undulatory. Undulatory contacts (>2" relief) are also common and tend to be restricted to the base of the fossiliferous beds. Mud injection structures are present where lithostatic stress caused a soft lime mud layer to inject into a weak zone in the overlying fossiliferous limestone bed. Grading and laminated intervals within the wackestones and packstones are rare; laminae are generally restricted to the barren to fossiliferous mudstone interbeds, although they are also uncommon in these beds. The packstones vary in thickness, but are typically thin- to medium-bedded, except in the uppermost part of the Lombard sections where several thick to very thick beds commonly occur. Most crop out as laterally discontinuous ledges, but some can be traced across an entire hillside with only minor breaks of cover.

Dark olive gray (5 Y 3/1), to olive gray (5 Y 4/1), to brownish gray (5 YR 5/2) colors are typically observed on fresh surfaces. Upsection in this lithofacies the limestone become slightly lighter, commonly displaying a pale brown (5 YR 5/2) to medium gray (N5) color. Weathered surface colors are extremely variable, generally ranging from yellowish gray (5 Y 8/1) to light gray (N7). In addition to the slightly lighter overall color than that of the rocks of the lime mudstone lithofacies, a lower total organic carbon content is suggested in these rocks by their weak to moderate petroliferous odor.

Bioturbation and burrowing are evident in many of the beds by the presence of small worm tube molds and casts, common random orientation and distribution of the biotic elements, and the rare mottled appearance on outcrop. The burrows are horizontal to gently inclined, and typically straight. No vertical burrows were found. Inclined dendroid burrows, up to 1.5 inches long, occur locally.

Chert nodules and stringers are abundant along discrete horizons, but generally are rare. Many display a grayish orange color (10 YR 7/4), but dark yellowish brown (10 YR 4/2) varieties are also common. Most of the chert nodules are small and irregular, in contrast to the well defined augen shape characteristic of the nodules in the lime mudstone lithofacies. Chert stringers are less common than nodules and seldom exceed four inches in thickness and fourteen inches in length.

Six southwest-projecting tongues are recognized in the Snowcrest Range area (plate 3). The three oldest tongues (IS-IIIS) pinch out in the Hogback Mountain-Sliderock Montain area. The three younger tongues (IVS-VIS) extend to the southwest edge of the thesis area, and beyond. These upper three tongues are part of a very thick fossiliferous wackestone-packstone lithofacies sequence which dominates the upper third to half of each Lombard section in the thesis area. This tongue breaks into the three younger tongues at positions progressively southwest of the termination point of tongue IIIS.

Microscopic analysis of this lithofacies reveals a diverse assemblage of microfacies dominated by sparse and packed biomicrites, biopelmicrites, biosparites, and biopelsparites. Many of these units are poorly washed and moderately sorted. The most significant and diagnostic contrast with respect to the lime mudstone lithofacies is the abundance of pelmatazoan and brachiopod debris and the virtual absence of sponge spicules (fig. 23). Ostracodes also display a marked decrease in abundance in these rocks.

This lithofacies contains a more diverse and abundant macrofaunal assemblage than does the lime mudstone lithofacies; this contrast of macrofossil- and microfossil-rich assemblages provides the main criterion for recognizing and separating the two

1mm

Figure 23. Photomicrograph of poorly washed echinoidal biomicrite. Note abundant macrofossils (echinoids, planispiral gastropods, pelecypods, brachiopods) and paucity of microfossils (sponge spicules, ostracodes). This is a common microfacies of the fossiliferous wackestone-packstone lithofacies. Unit 10, Sliderock Mountain. Plane polarized light.

lithofacies in the field. Additional distinguishing criteria for the fossiliferous wackestone-packstone lithofacies which are useful in the field include: (1) the absence to rare occurrence of laminites, (2) generally improved size sorting of the bioclasts, (3) increase in abundance of interparticle and/or intraparticle sparry calcite, and (4) the more resistant outcrop character.

Most of the transitions between the lime mudstone and fossiliferous wackestone lithofacies are gradual, although a few sharp changes do occur. As will be shown, many of the fossiliferous wackestone-packstone tongues contain a variety of microfacies, suggesting local variations in hydrodynamics associated with slight fluctuations in water depth, circulation, and/or sedimentation rate.

Tongue IS

Tongue IS is restricted to the northeastern end of the Snowcrest Range where it is exposed near the base of the Lombard at Sliderock and Snowcrest Mountains. Fossiliferous and sparsely fossiliferous wackestones compose most of this tongue, although fossiliferous mudstones occur in places between the wackestone beds.

The basal bed at Snowcrest Mountain is a sorted biopelsparite, containg 60 and 10 percent bioclasts and peloids, respectively. Disarticulated echinoids; trepostome, encrusting, and fenestrate bryozoans; and micritized foraminifera make up the majority of the skeletal fraction. Sponge fragments (rare) and spicules, and disarticulated ostracodes and brachiopods are subordinate. Sorting is excellent, as most of the grains are of coarse sand size (average diameter = 0.8 mm), and many of the grains are oriented parallel to bedding. Micrite (eight precent) is subordinate to sparry calcite (19 percent) and occurs as isolated interparticle patches, and as intraparticle fill in the bryozoans and ostracodes. Additionally, many of the bioclasts display micritic envelopes. Small, rounded intraclasts of sparse spicular biomicrite composition occur rarely, composing only three percent of the rock. Syntaxial overgrowths, originating from the numerous echinoid fragments, cement the bioclasts.

To the southwest this basal unit grades into a sparse echinoid biomicrite (sparsely fossiliferous wackestone). In addition to the abundant echinoid fragments, fenestrate and ramose trepostome bryozoan debris, brachiopod fragments and spines, and trilobite fragments and spines are present. Pelmatazoan ossicles and plates make up approximately 20 percent of the total constituents, followed by calcareous sponge spicules (ten percent) and the other elements previously mentioned (five percent). All of the bioclasts display evidence of slight to moderate abrasion. In addition, a bimodal size sorting is noted; the echinoid particles average 1.3 mm in diameter (very coarse sand size), while the surrounding elements occur as finely comminuted bioclastic debris. Peloids, up to 0.5 mm in diameter, are isolated and rare, making up less than three percent of the rock.

The overlying beds are similar, sparse to packed biomicrites. Sponge spicules, chiefly monactines, are common in many of these rocks and locally dominate the faunal assemblage. Echinoids are omnipresent, however, and commonly match or exceed the spicules in abundance, in contrast to the spicule and ostracode dominated rocks of the lime mudstone lithofacies. Articulated brachiopods, gastropods, and disarticulated and broken pelecypods are subordinate. Pelecypods are rare in the lower part of this tongue and peloids are less common above the lowermost beds. Several of the beds contain small chert nodules or stringers and a few beds are silty. Most of the rocks also display some degree of bioturbation, although the fossils are commonly aligned subparallel to bedding.

The tongue is best defined at its thinner southwest end, exposed at Sliderock Mountain, where it consists of 29 feet of fossiliferous and sparsely fossiliferous wackestones. The variable character of the rocks exposed in this tongue at Snowcrest Mountain may reflect rapid migration of lithosomes associated with the unstable nature of this end of the basin early in Lombard time, and with the very gentle slope of the basin floor.

Tongue IIS

This tongue displays a northeast-to-southwest distribution habit similar to tongue IS, but is thicker. The lack of exposures at this level at Hogback Mountain prohibit accurate projection of this tongue beyond a position midway between Hogback and Sliderock Mountains.

Fossiliferous mudstones are less common than in tongue IS and sponge spicules are subordinate to rare in the wackestone beds. Sparse biomicrites (sparsely fossiliferous wackestones) and packed, unsorted to sorted biomicrites and pelbiosparites dominate in this tongue. As in tongue IS, no packstone beds occur. Disarticulated and broken brachiopod valves and spines accompany echinoid ossicles and plates as the chief bioclastic constituents. The subordinate fauna consists of a diverse assemblage of gastropods, pelecypods, trilobites, and small, dissepimented horn corals. Bryozoans are rare, in contrast to their abundance in tongue IS, and consist of small fenestrate and trepostome fragments. Foraminifera occur locally. Sorting is characteristically poor to moderate. Evidence of bioturbation occurs in most of the rocks, and horizontal burrows are common. Inclined burrows are less abundant.

Several of the sparse biomicrites contain productid and chonetid brachiopods, including _Inflatia_ cf. _I. obsoletus_ Easton and several large specimens of _Chonetes_ sp. Thin, shaly limestone interbeds in these units also commonly bear a brachiopod-rich taxa containing numerous articulated and disarticulated, but unbroken, productid and chonetid brachiopods. These brachiopod-rich, sparse biomicrites are less common to the northeast, at Snowcrest Mountain, where fossiliferous wackestones (packed biomicrites and pelbiomicrites) are more abundant.

The few pelbiosparites in this tongue contain a faunal assemblage similar to the sparse biomicrites. Trilobite fragments, however, displaying excellent preservation of the internal canaliculi structures, are also moderately abundant. Size sorting is good, but a crude bimodality based on sphericity is present. The more elongate bioclasts display an average diameter of 0.37 mm (medium sand size), while the more spherical elements are only fine sand-sized (0.18 mm) on the average. Many of the grains are randomly oriented, display evidence of abrasion, and have micritic envelopes. Several elliptical to irregular, spicular micrite-filled patches are observed in thin section, suggesting burrowing and infiltration by overlying mud prior to complete lithification. Intraclasts are not present.

The upper part of this tongue reflects a gradual change in the depositional environment as the shallow water-dominated rocks grade vertically into deeper water rocks of tongue IIIS. This change is manifest in the increasing abundance of fossiliferous lime mudstones and concomitant decrease in macrofossils. As in tongue IS, the dominate lithology suggests shallow water deposition (as previously defined), but the occurrence of fossiliferous lime mudstones suggest some degree of variability in the depositional environment leading to an episodic lateral migration of the lithofacies on a scale finer than that used to define the six major tongues.

Tongue IIIS

Fossiliferous packstones and a very thick grainstone characterize this tongue, which extends southwest to a position in the vicinity of Sawtooth Mountain and Sunset Peak. This interval is covered in the overturned section measured at Sliderock Mountain, but is moderately to well exposed at Hogback and Snowcrest Mountains. Contrary to the relatively gradational transitions between lithofacies noted elsewhere, the base of tongue

IIIS is sharp.

Abrupt shoaling in the Snowcrest Mountain area is suggested by a 31 foot thick, cliff-forming, fossiliferous grainstone sequence which directly overlies a 40 foot thick section of "barren" to fossiliferous, slightly silty lime mudstones of tongue IIID (Plate 3). Bioclasts in this massive, sorted biosparite vary from medium sand- to very coarse sand-sized; the majority are coarse- to very coarse sand-sized (fig. 24). Quartz is absent and all of the allogenic material finer than 0.8 mm in diameter has been removed by winnowing currents or sediment bypass.

The fossil assemblage is similar to that observed in tongue IIS, although partial echinoid stems occur, and sponge spicules, pelecypods, and coral debris are absent. Many of the disarticulated brachiopod valves are thin-walled and highly convolute (spiriferids?), but most are unbroken. Likewise, many of the other randomly oriented bioclasts are disarticulated and slightly to moderately abraded, but few are broken. Syntaxial calcite overgrowths from the numerous echinoid fragments cement the bioclasts (fig. 24). Micrite is restricted to the intraparticle spaces.

Subordinate dolomite (less than ten percent), varying from finely mosaic to moderately coarse subhedral rhombs, occurs at the center of many of the monocrystalline spar-filled interparticle spaces, indicating post- or syncementation precipitation. Micritic envelopes are rare and thin on the bioclasts, although the foraminiferal tests are completely micritized.

At the southwestern end of the tongue, exposed at Hogback Mountain, the basal lithology consists of a sequence of thin- to

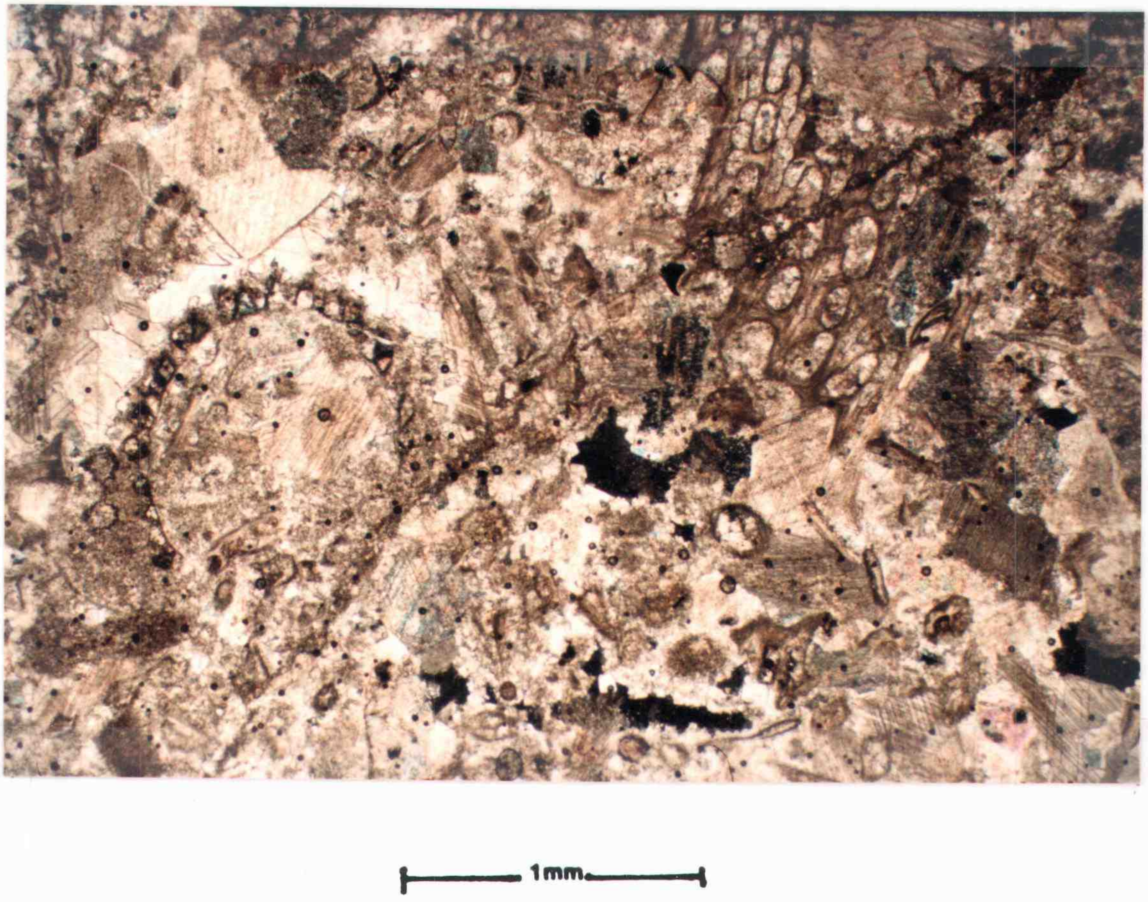


Figure 24. Photomicrograph of echinoid-bryozoan biosparite (grainstone) at the base of tongue IIIS (unit 41), Snowcrest Mountain section. Black spaces in center and lower center are reduced interparticle pores. Crossed nicols.

medium-bedded, poorly washed biosparites and sparse biomicrites separated by thin shaly partings or interbeds. Foraminifera are abundant and brachiopods are common, but echinoid and fenestrate bryozoan debris is predominant. Many of the fenestrate fragments occur as short, whole frond portions, rather than finely comminuted fragments. Size sorting is poor and most of the fossils are randomly oriented, suggesting post-depositional reworking by bioturbating organisms. Seven feet above the lowermost fossilferous wackestone, fenestral and trepostomous bryozoans predominate, supplemented by numerous foraminifera, echinoid and brachiopod fragments, and disarticulated ostracode carapaces. Small tabulate corals, <u>Michelinia</u> cf. <u>M. meekana</u> Girty, are also common (fig. 25). Micritic envelopes are rarely present on the bioclasts. Peloids and indeterminate micritic lumps, less than 300 microns in diameter, compose four percent of the total constituents.

Fossiliferous mudstones are common throughout this tongue, interbedded with fossiliferous wackestones and packstones in the southwestern end and sparsely fosssiliferous wackestones in the northeastern part of the tongue in the thesis area. Many of the mudstones are spicule- and ostracode-rich, but contain many echinoid plates and ossicles, and disarticulated and broken brachiopod fragments.

Above the basal grainstone at Snowcrest Mountain a series of alternating medium- and thick-bedded, sparse biomicrites, sparse spicular biomicrites, and sparse to packed spicule-ostracode biopelmicrites crop out. Laminations are generally absent and many of these beds display a swirled micrite texture and random

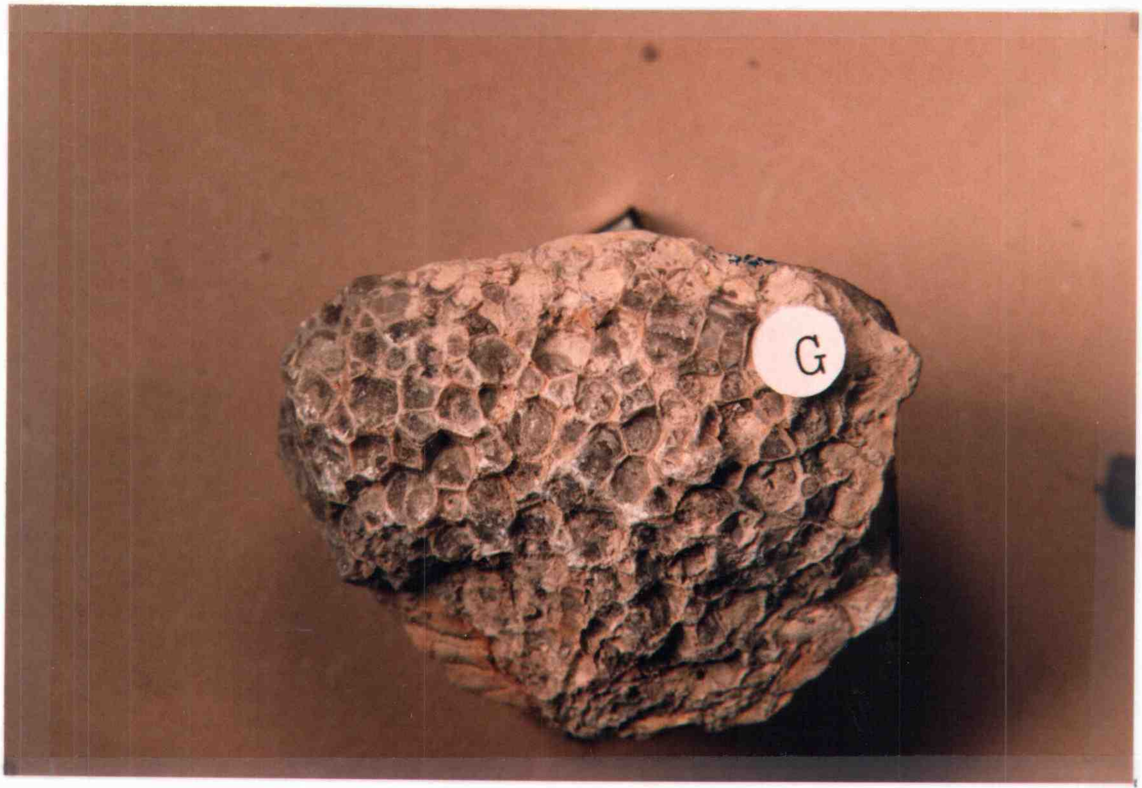


Figure 25. Representative specimen of the tabulate coral, Michelinia cf. M. meekana Girty, which occurs throughout fossiliferous wackestone-packstone tongues IIIS through VIS. Specimen in photo from unit 50, Sawtooth mountain section.

orientation and distribution of the bioclasts, indicative of bioturbation. Inclined and horizontal burrows are common throughout this lower section. Dendroid burrows are scarce. Echinoids and mollusks are common at all levels, but brachiopods are rare. Where brachiopods occur, several are commonly whole; productid varieties tend to predominate, although spiriferids are also common. Bryozoans are generally rare to absent, except in the sparse spicular biomicrite directly overlying the grainstone and at discrete intervals higher up in the section. Most of the bryozoans are encrusting forms or fenestrate fragments. Gastropods are characteristically large; some are greater than one inch in diameter. Dolomite is commonly present in amounts less than two percent.

The middle section of this tongue is covered at Hogback Mountain, but the upper part consists of a thin interval of fossiliferous mudstones and packstones. The mudstones contain a sparse assemblage of echinoid ossicles, disarticulated and broken brachiopods and pelecypods(?), and subordinately ostracodes. The packstones are sparse biomicrites (43 percent bioclasts) and packed biopelmicrites (58 percent allochems) with an echinoid- and pelecypod-rich faunal assemblage. A few of the pelecypods are articulated. Disarticulated trilobites and ostracodes are also common, in addition to the characteristic brachiopods and bryozoans which are less abundant. The bioclasts in the mudstones are typically oriented parallel or subparallel to bedding while those in the packstone beds are randomly oriented.

These packstones do not display evidence of washing, as the sparry calcite which is present (five percent) is generally restricted to the intraparticle spaces of the bioclasts, and the micrite matrix is rich in organic material, accounting for the dark color and very strong petroliferous odor of these rocks. Differential neomorphism of the micrite, probably associated with bioturbation, has locally created a patchy texture which is visible in thin section.

Peloids in the biopelmicrites only account for ten percent of the total constituents, but bioturbation and burial may have destroyed much of the original pelletal texture. The micritic peloids, which range in size from 40 microns to 200 microns in diameter, are coalesced into isolated, bulbous to slightly ovoid lumps (grapestones?) cemented by fine to moderately crystalline spar. In other parts of the rock the peloids have neomorphosed to microspar and have vague boundaries, imparting a remnant peloidal texture to the matrix.

Tongues IVS-VIS: Introduction

Tongues IVS, VS, and VIS branch from a major tongue whose thickness equals to exceeds that of tongues IS through IIIS combined (plate 3). Barren and fossiliferous mudstones are less common than in tongues IS through IIIS, however, and fossiliferous packstones are more abundant. Fossiliferous wackestones are ubiquitous and dominant throughout most of the major tongue. Sparsely fossiliferous wackestones are also moderately common, but primarily occur at the extreme northeast and southwest end of the thesis area. At least two thin fossiliferous grainstone beds occur in the uppermost part of this principle tongue, and a limestone lithoclast conglomerate caps the lithofacies at Sawtooth Mountain.

Owing to the more resistant, ledge-forming character of the wackestones and packstones in this tongue, it can be easily recognized throughout the Snowcrest Range and provides a useful index interval for determination of relative position in the Lombard section. The majority of the small to moderate hills which are underlain by Lombard Limestone are capped by the fossiliferous limestones of this principle tongue and the triad of related tongues (IVS-VIS) to the southwest.

The three upper tongues originate between Hogback Mountain and Sawtooth Mountain, and extend progressively farther to the southwest with decreasing age. These tongues are slightly thicker than the lower three tongues, although the subtle faunal and textural changes noted from the root to the end of the tongue in tongues IS through IIIS are also characteristic of these upper tongues. That is, sea level fluctuations and associated lithotope migrations are recognized in the rock record of these tongues, but these are too fine to accurately resolve and correlate in this investigation.

Tongues IVS-VIS: Lower part

The lower one hundred feet of this principle tongue, correlative with tongue IVS on the basis of similar vertical variations in fauna and lithology, consists of fossiliferous and sparsely fossiliferous wackestones which pass into a thin capping sequence of fossiliferous wackestones and packstones. Subordinate, poorly exposed fossiliferous lime mudstone beds crop out between the wackestones and packstones.

Sparsely fossiliferous wackestones, subordinate fossiliferous wackestones, and isolated fossiliferous mudstones characterize the lower part of this tongue at Snowcrest Mountain. Echinoid and brachiopod debris, and whole foraminifers compose most of the bioclastic fraction, although ostracodes, bryozoans, and sponge spicules (rare) also occur in minor abundance. Articulated brachiopods occur are less common.

A few of the beds are silty and dolomitic. Finely crystalline dolomite rhombs locally compose up to twenty percent of the sparse biomicrites and display a distribution habit controlled by previous bioturbation. Most of the bioclasts are broken, but display only slight evidence of abrasion. A few contain micritic envelopes, although the foraminifera are completely micritized.

Textural inversion is evident as all of the bioclastic material finer than 0.2 mm in diameter (fine sand size) is absent, although micrite and microspar make up almost one-half of the total constituents. The swirled texture in the micrite and random orientation and distribution of the bioclasts, combined with the patchy dolomite distribution are diagnostic of bioturbation.

To the southwest, the majority of the beds in this one hundred foot thick interval are sparse to packed biomicrites and biopelmicrites. Peloids, ranging from 25 to 300 microns in diameter, compose up to 50 percent of the total constituents in the biopelmicrites (fig. 26). The peloids display two styles of occurrence, (1) as separate bodies cemented by limpid, monocrystalline to coarsely crystalline sparry calcite, or (2) as

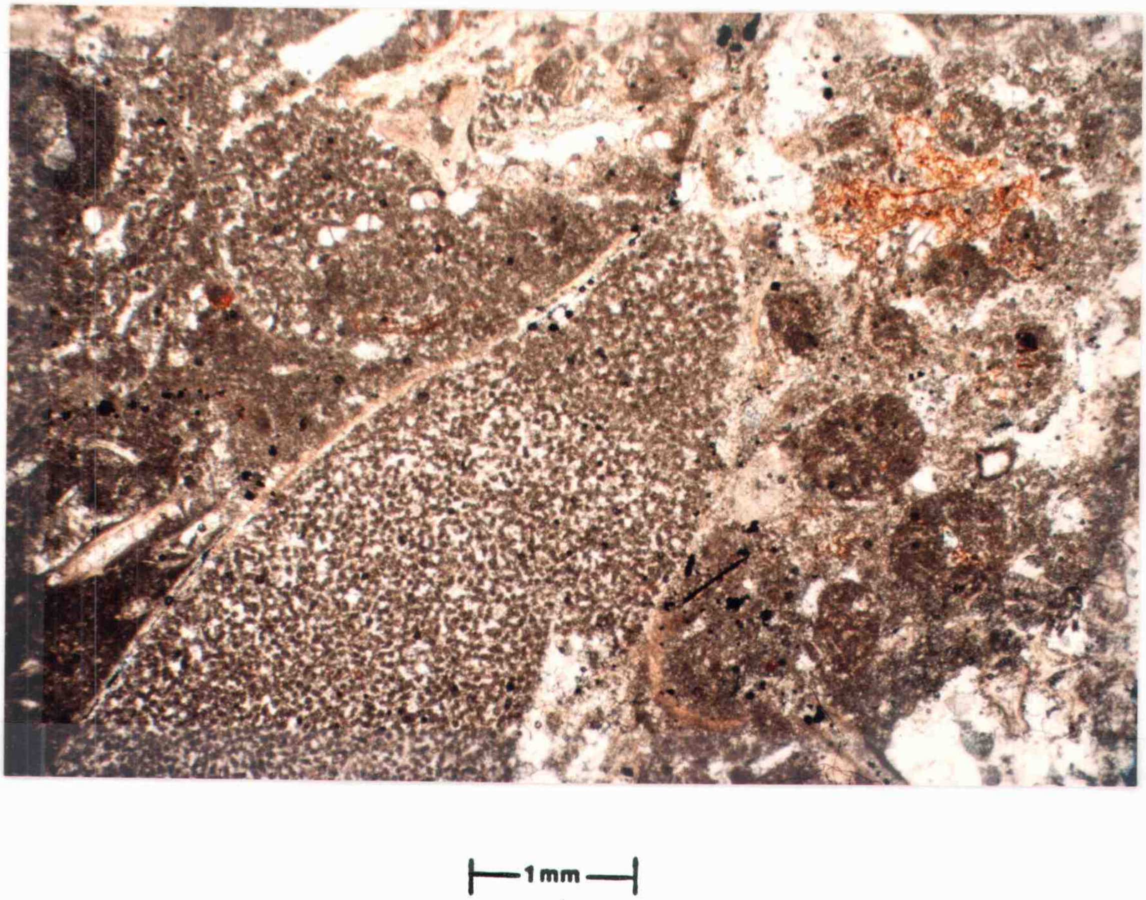


Figure 26. Photomicrograph of poorly washed biopelmicrite. Note limpid sparry calcite cementing peloids in upper left part of photo and inside articulated brachiopod. Spar also filling zooecia of fenestrate bryozoan fronds. Large, spherical brown objects in right half of photo are micrite-filled autopores of a ramose bryozoan fragment. Interpeloidal spar decreases in abundance outside of photomicrograph. Unit 30, Sliderock Mountain I section. Plane polarized light.

tightly packed peloids with moderately common concavo-convex to irregulary deformed contact boundaries.

Bioclasts compose up to 58 percent of the total constuituents in these beds and consist primarily of disarticulated echinoids, brachiopods, foraminifera, corals, and trilobites. Articulated and disarticulated ostracodes, pelecypods, sponge spicules, and conodonts occur rarely. Slightly abraded, dissepimented solitary rugose corals (Siphonophyllia sp.) are common in the lower part of this interval at Hogback and Sliderock Mountains.

Endothyrid foraminifera compose up to fifteen percent of the rock and are the chief constituent in a few of the biomicrites (fig. 27). Most of the formainifers are benthic or planktonic, although encrusting varieties are additionally present in a poorly washed biopelsparite near the top of this interval at Sliderock Mountain. A two foot thick bed containing closely packed orthotetacean brachiopods in a death assemblage immediately underlies this foraminifera-rich sequence.

Rhabdomesid and indeterminate dendroid trepostomous bryozoans are abundant and progressively increase in abundance upsection, ultimately dominating the faunal assemblage in the capping packstone beds. Fenestrate bryozoans are proportionately less abundant than the ramose forms. Bryozoans are less abundant at the Sliderock Mountain section than at Hogback Mountain, yet compose an integral part of the bioclastic fraction there. Despite the variability in dominant fauna in each bed, pelmatazoan- and brachiopod-rich biomicrites and biopelmicrites characterize this interval.

Figure 27. Photomicrograph of foraminiferal biomicrite in tongue IVS. Sparry calcite fills chambers of most foraminifers. Replacement chert acting as local intraparticle fill. Unit 34, Hogback Mountain section. Crossed nicols.

The uppermost packstone bed which defines the top of this interval at Sliderock Mountain is an unsorted biopelsparite which contains 47 percent bioclasts, 26 percent peloids, and seven percent intraclasts. All of the bioclasts are subrounded to well rounded and have micritic envelopes. Encrusting foramininfera are commonly found on ghosts of bioclasts which have been completely replaced by limpid sparry calcite and are recognizable only by their shape and micritic envelopes. The intraclasts are chiefly elongate, abraded fossiliferous wackestone fragments which have also been partially micritized.

Microscopic examination of the poorly exposed fossiliferous lime mudstone interbeds reveals the paucity of sponge spicules and abundance of echinoid ossicles and plates, and broken brachiopod valves. Articulated and broken ostracodes are also present, but generally in subordinate amounts. Sorting of the bioclasts is typically poor and most displaty a moderate to good preferred orientation habit.

In general, bioclasts increase in abundance upsection, although little evidence for increasing maturity or shoaling upsection is recognized in this lower interval. Most of the beds display moderate to excellent size sorting of the allochemical constituents; very few beds contain bioclastic material finer than 0.22 mm (very fine sand) and many exclusively contain bioclasts greater than 0.5 mm in diameter (medium sand size). The echinoid, brachiopod, and coral debris commonly exeed the other bioclasts in size, often by at least one order of magnitude with respect to the Wentworth grain size scale. This bioclast size variation may reflect variable source areas for the individual taxa.

Despite the good sorting noted in most of these rocks several of the beds contain fossil assemblages which are oriented parallel or subparallel to bedding, and few of the bioclasts are abraded. Bioturbation and/or discrete burrows, however, are evident in most of the rocks, regardless of the degree of preferential orientation of the bioclasts. Patchy and/or swirled micrite textures, accentuated by differential neomorphism, are very common. Micrite typically exceeds sparry calcite as the matrix material, except in the isolated biopelsparite beds. Sparry calcite is common, however, filling the intraparticle spaces in chambered and articulated bioclasts, and in random sheltered areas between bioclasts.

Tongue IVS

Fossiliferous wackestones at the base of Tongue IVS are in sharp contact with the underlying fossiliferous micrites and sparsely fossiliferous wackestones of the top of tongue IIID. This contact is covered at most measured section sites, but is well exposed at Sawtooth Mountain where the contact is sharp and undulatory. Where this contact is covered or poorly exposed, the base of the tongue is taken at the abrupt occurrence of fossiliferous wackestones above the covered interval.

The basal beds contain a diverse and abundant macrofossil assemblage dominated by articulated and disarticulated brachiopods, including Spirifer cf. S. brazerianus Girty, and pelmatazoan plates and ossicles. Subordinate taxa throughout the basal part of this tongue include bryozoan, pelecypod, coral, ostracode, and foraminifera debris, and rare sponge spicules.

Peloids only account for eleven percent of the total constituents in the basal wackestones and decrease in abundance upsection. Many of the peloids are clustered, although the majority occur as isolated individuals; the peloids are typically cemented by limpid, mosaic to coarsely crystalline sparry calcite in both types of occurrences. A five inch-thick storm layer containing a dense accumulation of broken and slightly abraded bioclastic debris, oriented subparallel to bedding, occurs three feet above the base of this tongue at Sawtooth Mountain.

The overlying fossiliferous wackestones contain fewer peloids. Bryozoan fragments additionally are very common, in contrast to their subordinate occurrence in the basal wackestones. Gastropods are present locally. Fossiliferous packstones (packed biomicrites and packed, poorly washed biosparites) characterize the upper part of the tongue, except at Hogback Mountain where sparsely fossiliferous wackestones bearing a similar faunal assemblage occur at this level.

Disarticulated echinoid ossicles, plates, and partial stems are the chief constituents in the packstones. Ramose bryozoans, brachiopods, gastropods, foraminifera, and pelecypods(?) are additionally present. Ostracodes, sponge spicules, and conodont fragments are absent. Peloids are also missing. Sparry calcite fills most of the intraparticle spaces, although no geopetal fill textures occur. As in the underlying wackestones, the bioclasts display no preferred orientation. Differential neomorphism, creating irregular pockets and seams of pseudospar and/or microspar in the micrite matrix, is ascribed to bioturbation prior to diagenesis. Very few of the bioclasts display any evidence of abrasion.

The upper contact with tongue VD is poorly defined because of cover. Sparse spicular biomicrites, however, crop out within ten feet of the uppermost fossiliferous packstone beds exposed at the top of tongue IVS, suggesting a potentially rapid shift in depositional environment.

Tongues IVS-VIS: Upper part

Fossiliferous wackestones and packstones, and subordinate fossiliferous grainstones, mudstones, and sparsely fossiliferous wackestones characterize the upper part of the major tongue, above the one hundred foot thick lower interval previously described. The wackestone and packstone beds vary in thickness, but tend to be thicker overall than in the lower tongues. The packstones display the greatest thickening upsection, however, as most are thin- to medium-bedded throughout the lower and middle parts of the tongue, but medium- to thick-bedded in the upper part. Chert is rare to absent on outcrop.

Fossiliferous wackestones predominate throughout the major tongue, as previously discussed, but packstones equal to locally exceed the wackestones in abundance in the upper part of the tongue. This upper interval is largely covered at Snowcrest Mountain. The few beds which crop out are sparsely fossiliferous wackestones and subordinate fossiliferous wackestones.. Sponge spicules and ostracodes are rare in these beds. Pelmatazoan ossicles and plates, brachiopod fragments, and gastropods compose most of the faunal assemblage. Sorting is poor to moderate, and very few of the fossils are oriented parallel to bedding.

The wackestones which characterize this interval are chiefly sparse to packed biomicrites similar to those described in the lower interval. Isolated poorly washed biosparites are also present. The dominant faunal elements in the wackestones are the same as those in the lower wackestones, but gastropods, pelecypods, and less commonly ostracodes occur with greater frequency. Pelecypods are particularly common in the lower part of this upper interval. Peloids are rare in the thin sections analyzed throughout this interval, although a relict peloidal texture is present locally.

Bryozoans are common throughout this interval in all of the sections analyzed southwest of Hogback Mountain. Northeast of this location bryozoans are abundant only in the uppermost fossiliferous wackestones, and are typically subordinate to pelmatazoan and brachiopod debris in the remainder of the interval. Ramose trepostome and cryptostome forms occur with the greatest frequency (fig. 28). Indeterminate dendroid, trepostomous bryozoans occur at several levels in both fossiliferous wackestone and packstone beds; most are less than two to three millimeters in diameter and branch several times. The majority of the dendroid bryozoans are broken, but occur as articulated, branching forms up to 1.5 inches in length which lie parallel to bedding. Fenestrate bryozoans are also commonly present, but tend to be concentrated in the uppermost wackestone beds and in the packstone beds.

Coralliferous debris is not common in most of the wackestones, but corals make up a significant portion of the faunal assemblage

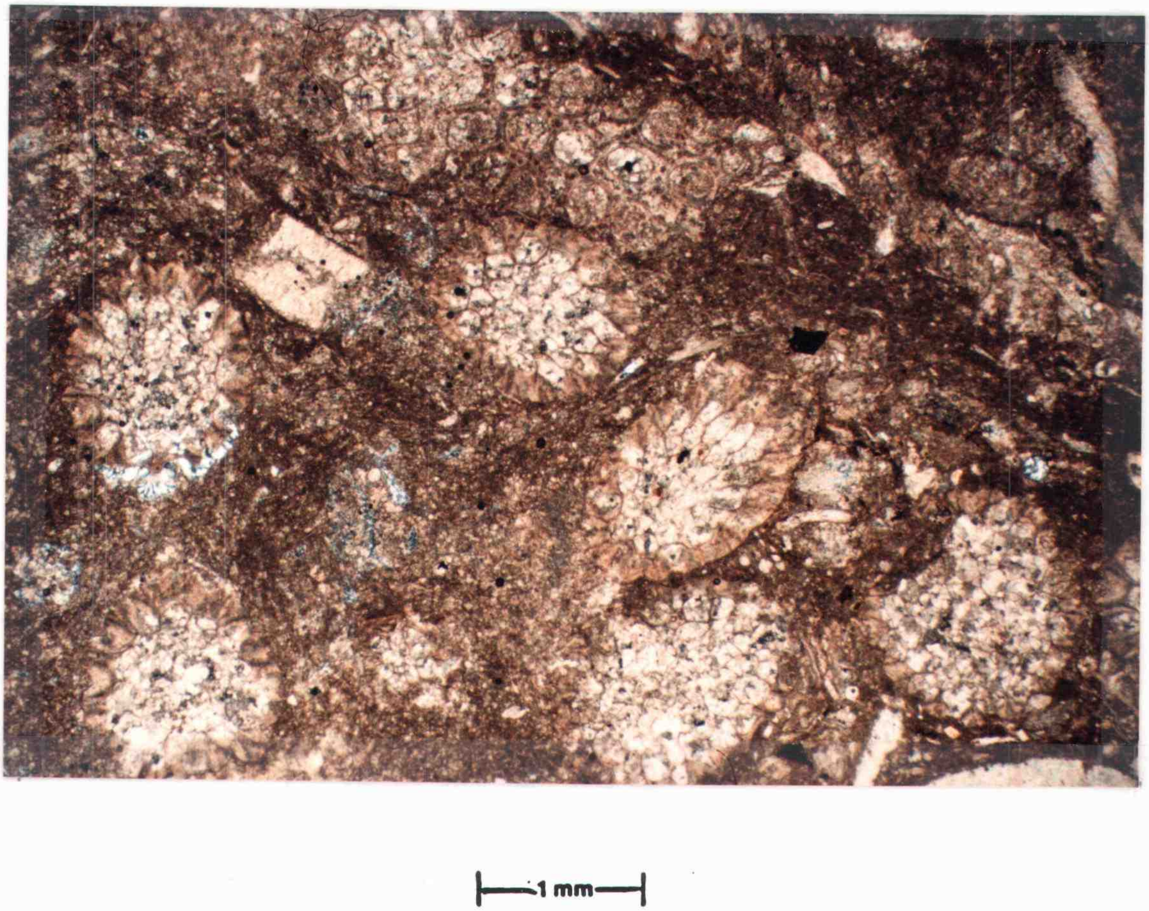


Figure 28. Photomicrograph of bryozoan biomicrite. Note intraparticle sparry calcite and local replacement by chert. Unit 39, Sawtooth Mountain section. Crossed nicols.

in the uppermost wackestone beds at Sliderock Mountain and in isolated beds elsewhere in the middle part of this interval. The corals which occur at Sliderock Mountain include Amplexizaphrentis sp., Siphonophyllia sp., Vesiculophyllum sp., and indeterminate amplexoid corals. The occurrence of Vesiculophyllum sp. (fig. 29) suggests structural complications in the upper part of the Lombard here, as this coral seldom occurs in rocks younger than late middle Meramecian (Foraminifera Zone 13). Such complications were not recognized in the field, although some fault thickening, obscured by thin covered intervals, may have occurred here. The other corals present in this interval, however, are diagnostic of a Mississippian age; Siphonophyllia sp. indicates that these rocks are Chesterian in age (Sando and Bamber, 1979; W. J. Sando, written communication, 1985).

In addition to the corals, several brachiopods in this interval are also diagnostic of a Late Mississippian age (specifically Foraminifera Zones 16, 17, and the lower part of 18; J. T. Dutro, Jr., written communication, 1985). These brachiopods include Antiquatonia sp., Anthracospirifer curvilateralis Easton, Composita sp., Composita cf. C. sulcata Weller, Diaphragmus cf. D. cestriensis Worthen, Flexaria sp., Inflatia sp., and Inflatia cf. I. obsoletus Easton (fig. 30).

Evidence of bioturbation is highly variable from bed to bed, but some reworking of the fossiliferous lime muds prior to cementation is evident in most of the wackestones. Most of the beds display a swirled texture and/or differential neomorphism with a patchy habit. Burrows are moderately common, and tend to be

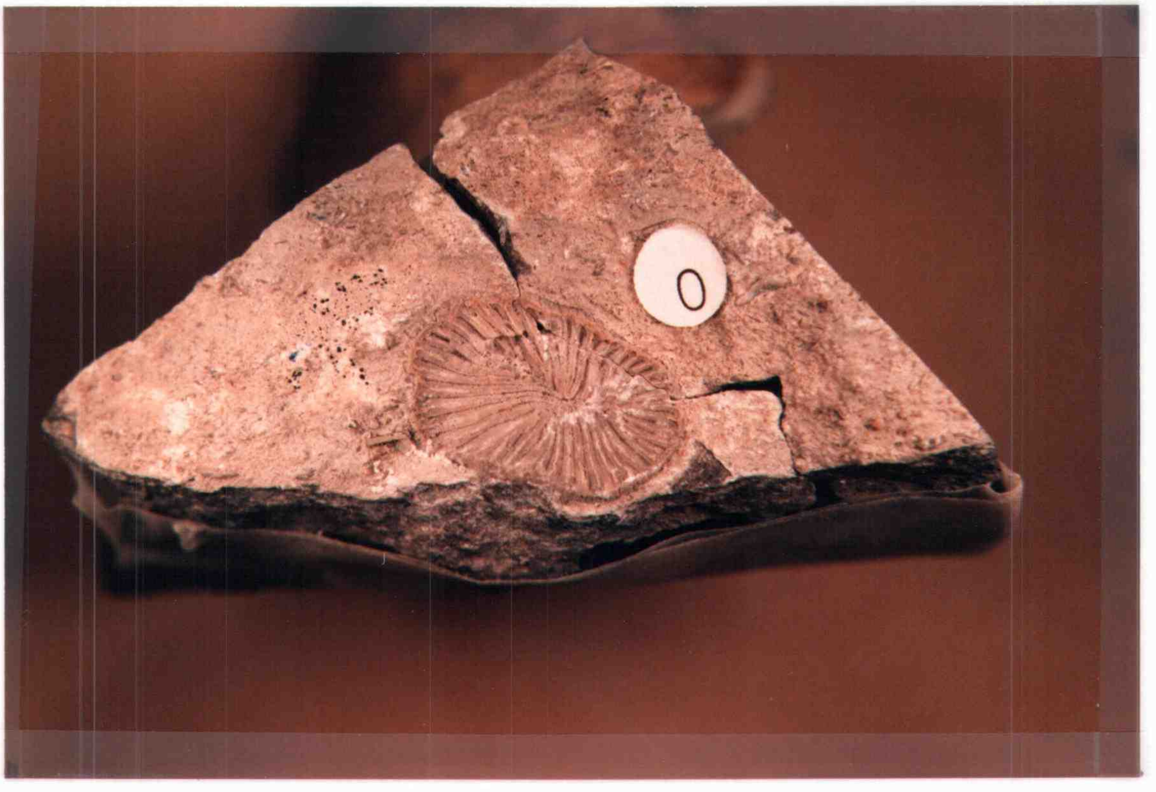


Figure 29. Specimen of Vesiculophyllum sp. from unit 11, Sliderock Mountain II section. Letter "O" is approximately 2.5 mm in diameter.

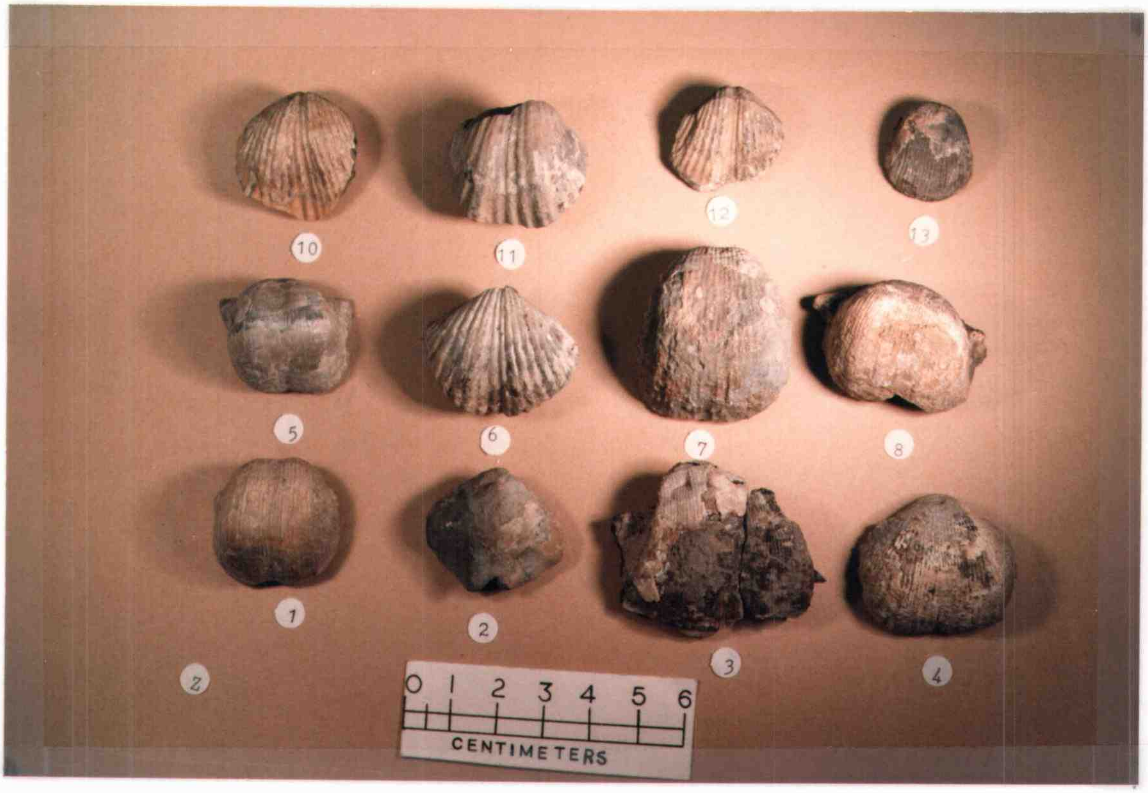


Figure 30. Brachiopods collected in upper part of Lombard Limestone at Sliderock Mountain (units 10 and 11, section II). Numbers in parentheses correspond to numbers in photograph.
Inflatia cf. I. obsoletus Easton (1, 5)
Composita cf. C. sulcata Weller (2)
Antiquatonia sp. (3, 4)
Anthracospirifer curvilateralis Easton (6, 10, 11, 12)
Flexaria sp. (7)
Inflatia sp. (8)
Diaphragmus cf. D. centstriensis Worthen (13)

horizontal to inclined; vertical burrows occur locally.

Small, moderately rounded to predominantly angular phosphatic fragments are present in most of the wackestone analyzed in thin section. Many probably represent broken conodonts, although length and concavity of some of the fragments suggest an inarticulate brachiopod origin. Cochliodont fish teeth also occur locally (W. J. Sando, written communication, 1985).

Fossiliferous wackestones and mudstones are present in this interval at Sunset Peak. The Lombard section here is overturned and truncated by a back-limb thrust which has superposed Mission Canyon Limestone units over rocks of the upper part of the Lombard. The uppermost part of the Lombard section is covered and believed to be underlain by calcareous shale, fossiliferous wackestones, mudstones, and packstones similar to those found at this level at Sawtooth and Hogback Mountains. The uppermost fossiliferous wackestones and thin packstone interbeds which crop out at Sunset Peak are very different from those at the aforementioned locations. Many of these beds are very silty, containing up to 22 percent quartz silt and fine sand. Several carbonaceous flakes and fragments are additionally seen on outcrop; microscopic examination reveals that these are wood(?) fragments with well preserved vascular structures (fig. 31). Dark brown to black threads of organic matter anastomose throughout the micritic matrix. Laminations are absent and the bioclasts are randomly oriented in most of the beds, suggesting bioturbation. Horizontal burrows are ubiquitous; in several places the fossils parallel the burrows, suggesting that the bioclasts were pushed aside during

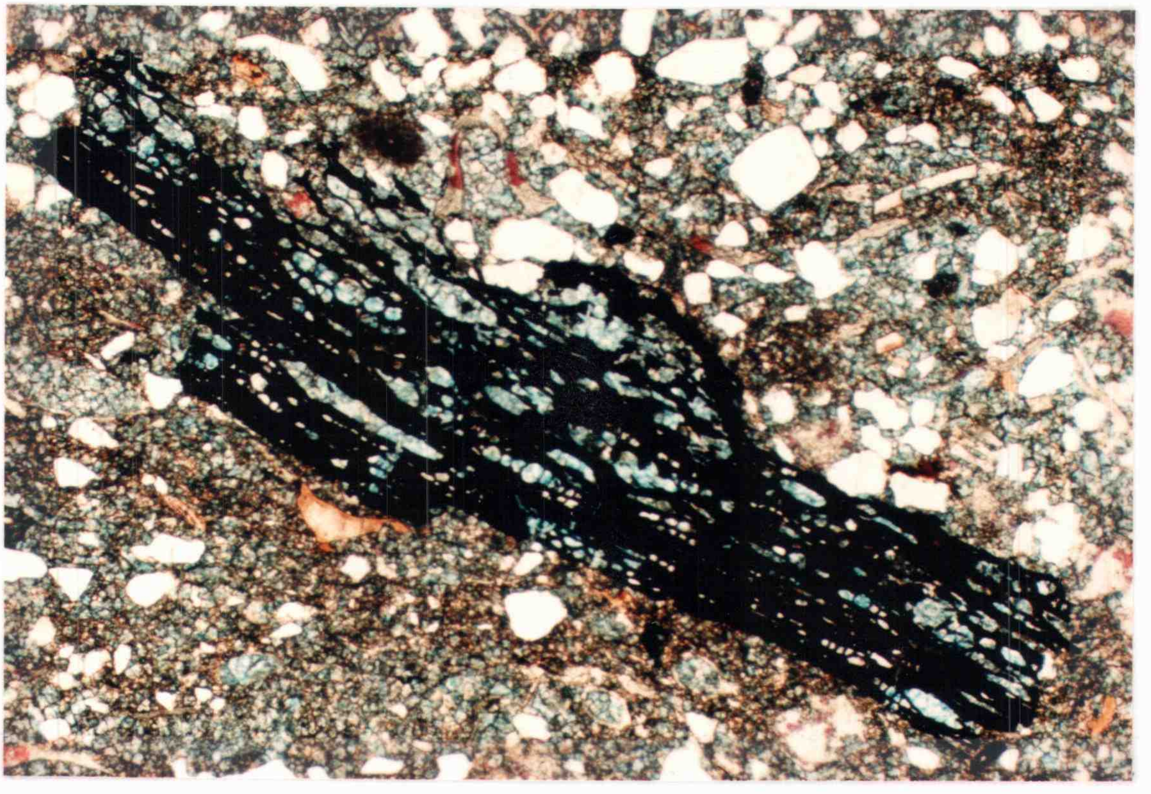


Figure 31. Photomicrograph of wood(?) fragment in silty biomicrite. Unit 13, Lombard Limestone, Sunset Peak section.

excavation of the burrows. Pelmatazoan, brachiopod, pelecypod, and ostracode debris dominates the bioclastic assemblage. Gastropods, foraminifera, and sponge spicules occur rarely or are absent. Most of the faunal elements are disarticulated or broken, but few are abraded, with the exception of some of the echinoid fragments.

Stratigraphically below these wackestones and packstones at Sunset Peak several fossiliferous mudstone and sparsely fossiliferous wackestone beds crop out. The fossil assemblage in these rocks is similar to that in the wackestones, but sponge spicules are more abundant in some beds. Quartz is additionally less common, seldom exceeding three percent. Both the wackestone and mudstone beds are rather anomalous when compared with laterally equivalent units to the southwest and northeast. While the wackestones are believed to be autochthonous with respect to the overlying Late Paleozoic rocks, the fossiliferous mudstones may be allochthonous. No evidence for a fault between these two series of beds is recognized in the field, but unrecognized thrusting along bedding planes may have occurred in this area.

Fossiliferous packstone beds crop out between the wackestones at several levels within this upper interval. Thin to medium beds predominate, although these packstone beds, in general, increase in thickness and lateral continuity upsection and to the southwest. The majority of the packstones in this interval and the previously described lower interval are laterally discontinuous in outcrop. Some of the beds which can be traced along strike pass into fossiliferous wackestone beds, reflecting a lateral change in the abundance of bioclasts. In contrast to these thin to medium beds, the uppermost packstones are predominantly medium- to thick-bedded and massive, forming resistant ledges and isolated, thin cliff sequences. Very thick beds occur rarely. The upper part of this interval is predominantly to completely covered at Clover Divide, Sunset Peak, and Snowcrest Mountain, although float typically denotes the presence of a covered wackestone and packstone lithology at this level.

A few of the packstone beds consist of thin (inches thick) fossil-rich beds separated by less fossiliferous, micrite-rich partings or seams. Many of these very thin packstone layers contain a different predominate faunal element than in the overlying and underlying thin layers. A constant diversity is generally recognized throughout the entire packstone bed, but the abundance of individual taxa in each sublayer commonly varies.

Petrographic analysis reveals that the chief packstone microfacies are packed biomicrites and biosparites, poorly washed (packed) biomicrites and biosparites, and packed biopelmicrites. Echinoids, brachiopods, bryozoans, and corals commonly make up the bulk of the packstones, although no one faunal element is ubiquitously dominant. Subordinate to locally abundant bioclasts include pelecypods, foraminifers, gastropods, trilobites, red(?) algae, orthoconic nautiloids, and indeterminate phosphatic skeletal fragments. Ostracodes and sponge spicules are characteristically rare to absent. Bioclasts typically exceed 40 percent of the total constituents. Peloids also occur locally, composing up to 26 percent of the rock.

Bryozoans increase in abundance upsection and dominate the bioclastic assemblge in the uppermost packstone beds. Ramose trepostome (including rhabdomesids) and cryptostome varieties occur with the most frequency throughout most of this interval. Fenestrate bryozoans, though subordinate to uncommon in the lower parts of this interval, are commonly dominant in the uppermost packstone beds. Encrusting bryozoans occur locally.

Large solitary corals (Siphonophyllia sp.; fig. 32), dissepimented rugose corals (Amplexizaphrentis sp.), and tabulate corals (Michelinia cf. M. meekana Girty) are very abundant in the thick uppermost packstones and dipslope float at Sawtooth Mountain. Identical corals are present in similar packstone beds at the Red Rock River (tongue VIS) and Sliderock Mountain sections.

A diverse brachiopod assemblage, dominated by productid brachiopods, is also present in the packstones in this major tongue. In addition to the brachiopods previously mentioned from Sliderock Mountain and in the fossiliferous wackestones, Antiquatonia cf. A. pernodosa Easton and Inflatia cf. I. richardsi Girty are also present (fig. 33).

Northeast of Sawtooth Mountain disarticulated echinoids and brachiopods predominate, and bryozoans are subordinate. The subordinate fuanal assemblage is similar to those to the southwest, but foraminifera and conodonts are absent or not recognized at Hogback Mountain. Thick packstone beds are missing or covered at Sliderock Mountain, although a series of thin, echinoid- and bryozoan-rich packstone beds crop out within a 35 foot thick

Figure 32. Solitary rugose coral, Siphonophyllia sp., from upper part of Lombard Limestone (unit 50, Sawtooth Mountain section). Scale is in centimeters.

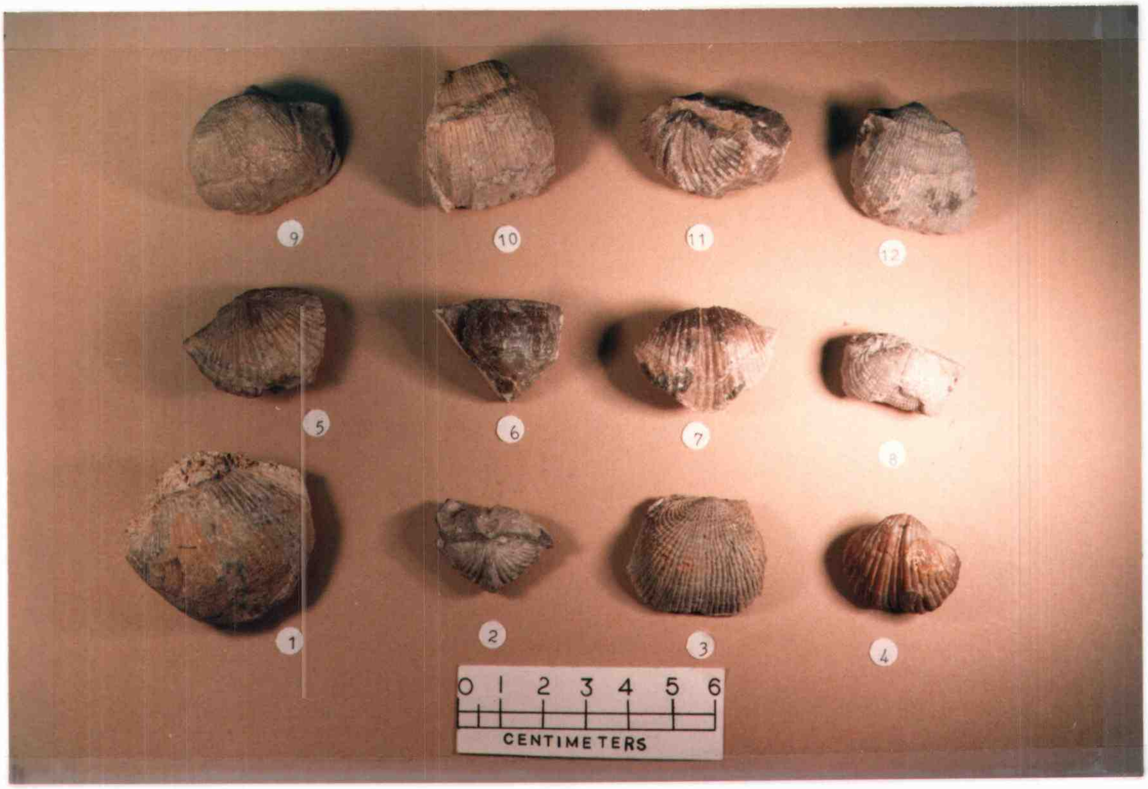


Figure 33. Brachiopods collected in units 13, 22, and 50, Lombard Limestone, Sawtooth Mountain section. Numbers in parentheses corrsepond to numbers of photograph.

Spirifer cf. S. brazerianus Girty (1)
Anthracospirifer curvilateralis Easton (2, 4, 5, 7, 11)
Antiquatonia aff. A. pernodosa Easton (3, 8, 9, 10, 12)
Inflatia cf. I. richardsi Girty (6)

fossiliferous wackestone (sparse to packed biomicrite) sequence near the top of this interval. Bryozoans in these thin interbeds are chiefly fenestrates, cystoporids, and indeterminate ramose cryptostome(?) varieties (W. J. Sando, written communication, 1985).

Peripheral boring and micritic envelope development is common in most of the allochemical constituents in all of the upper packstone beds and several of the lower beds in this upper part of the major tongue. Bioturbation is ubiquitous as well, although some of the patchy spar texture in the micritic matrix is probably the result of weak to moderate washing by oscillating currents or storm events. With the exception of the local trilobite fragments, very few of the bioclasts display evidence of extensive reworking and abrasion. Burrows are also common, varying from predominantly horizontal and inclined to less commonly vertical. Size sorting is generally moderate to good in all of the packstone beds, as bioclastic debris finer than approximately 0.25 mm in diameter (fine sand) is commonly absent to rare.

Stromatactoids are not recognized in the field or in thin section, nor do any of the aligned fossils display a steeply inclined habit which distinguishes Waulsortian-type mud mounds. Many of the packstones crop out discontinuously and are difficult to trace laterally. In many outcrops, where lateral continuity can be demonstrated, the packstone beds pass into wackestone beds and vice versa, suggesting rapid, small scale variations in productivity and/or the physical environment over short distances. The packstones in the lower part of this upper interval and the lower one hundred foot thick interval tend to be laterally discontinuous, suggesting a patchy distribution. The uppermost packstones, however, can be traced along strike for a considerable distance, suggesting a more widespread, sheet-like(?) geometry. Cross-bedding and ripple textures are ubiquitously absent or not recognized in the packstone and wackestone beds throughout the Lombard in the study area.

Tongues IVS-VIS: Uppermost part

One washed packstone (poorly washed oobiosparite) bed and two fossiliferous grainstone (sorted biosparite) beds crop out stratigraphically above the uppermost, thick-bedded packstones on a dip slope at Sawtooth Mountain.

The grainstones contain a moderately well sorted faunal assemblage similar to the packstones. Elliptical peloids, averaging 700 microns in diameter are well preserved and commonly surrounded by the coarse, slightly dirty, syntaxial calcite cement which binds the allochemical constituents. Ooliths are rare, composing one to two percent of the total constituents. Micrite is rare, occurring exclusively as intraparticle fill.

Ooliths compose up to eight percent of the oobiosparite. Most are cored by foraminifers, display an overlapping concentric and radiating cortical fabric, and have a slightly abraded, but unmicritized rim (fig. 34). Where the ooliths, which average 600 microns in diameter, are in contact with adjacent allochems the cortices are commonly deformed, indicating the soft, pliable character of the ooilith cortex during deposition. Rare, silty

Figure 34. Photomicrograph of sorted biosparite. Syntaxial calcite overgrowths cementing allochemical constituents. Note overlapping concentric and radiating cortical fabric and micritized foraminifer core. Unit 49, Sawtooth Mountain section. Plane polarized light.

micrite mud chips (angular intraclasts) are also present.

The top of this major tongue and tongue VIS to the southwest is covered throughout the Snowcrest Range, except at Sawtooth Mountain where a thin, lenticular(?) limestone lithoclast conglomerate crops out beneath a limy shale sequence at the base of a large dip slope underlain by the uppermost packstones and grainstones (fig. 35). The predominant granule- to cobble-sized clast lithologies include unfossiliferous silty micrites, sparse biomicrites, packed biomicrites, unfossiliferous dismicrites, and rare fluorapatite pellets (fig. 36). All of the lithoclasts are subrounded to rounded and display moderate to excellent sphericity.

The subordinate matrix, composing only 20 percent of the total rock, consists of disarticulated, crushed, and commonly abraded bryozoans, brachiopods, echinoids, foraminifera, trilobites, and red algae(?) fragments in a micritic matrix (fig. 36). No preferred orientation is observed in either the matrix allochems or lithoclasts. Quartz silt to very fine quartz sand is typically minor, although quartz-rich (up to 20 percent) pockets occur locally. Most of the sparry calcite occurs as shelter and interparticle fill between the abraded clasts. Shelter, intraparticle, interparticle, fracture, and intercrystal porosity locally accounts for three to four percent of the total rock volume (visual estimate). Piercement features and concavo-convex contacts are locally present between adjacent clasts, suggesting that some of the clast were soft and deformable during deposition (figs. 35, 36).

The uppermost contact of the fossiliferous wackestone-packstone lithofacies with the overlying calcareous

Figure 35. Limestone lithoclast conglomerate exposed at base of dip slope on hill (9,566') just west of Sawtooth Mountain (unit 53; W 1/4, SW 1/4, section 8, T. 12 S., R. 5 W.). Note variable clast sizes and lithologies.

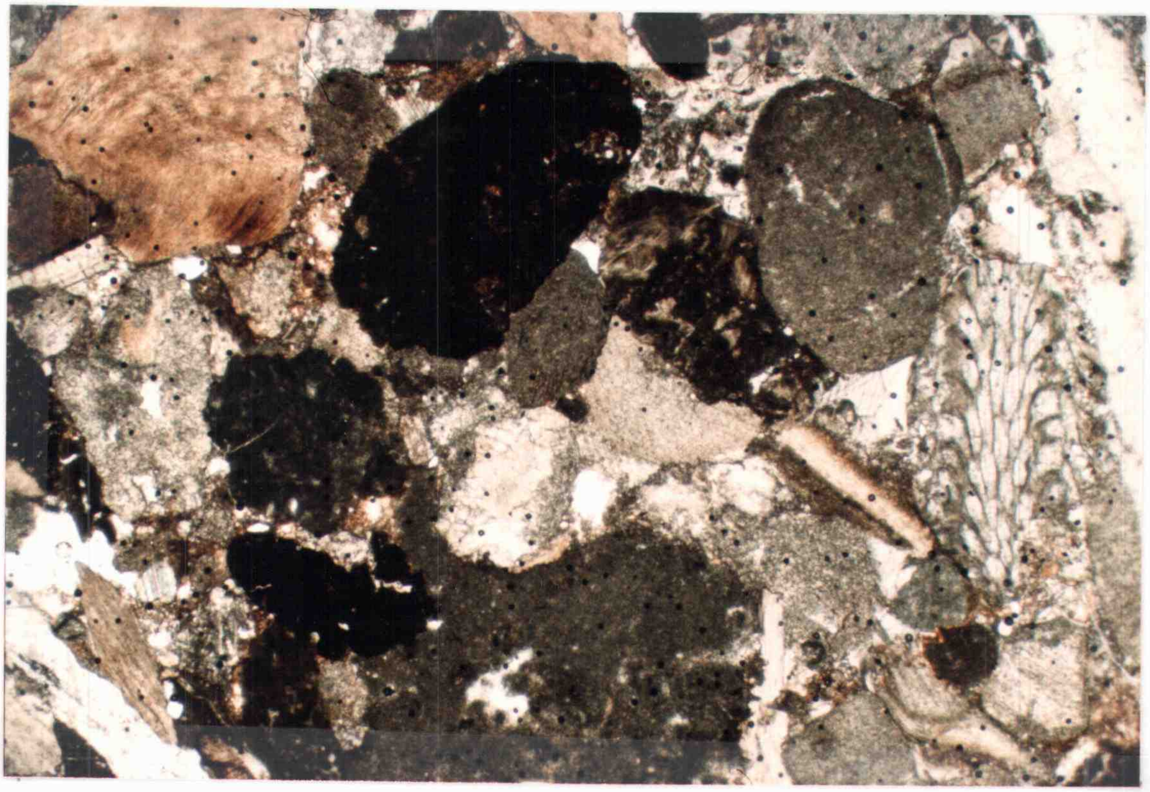


Figure 36. Photomicrograph of finer fraction of limestone lithoclast conglomerate. Note variety of carbonate lithologies represented by intraclasts and granules, and variable degrees of rounding. Ramose trepostome bryozoan fragment in matrix at right edge of photomicrograph. Unit 53, Sawtooth Mountain section. Plane polarized light.

shale lithofacies is covered throughout the thesis area. The relatively thin covered interval, only eight feet thick, between the limestone lithoclast conglomerate and overlying shales suggest that the transition is relatively sharp. A similar conclusion is drawn at Sliderock Mountain where a pronounced change in slope coincides directly with an abrupt change from shale and fossiliferous wackestone and packstone float to exclusively shale float above.

Tongue VS

Tongue VS is only exposed in the thesis area at Clover Divide and Red Rock River. At the latter section interbedded fossiliferous mudstones and packstones crop out at the top of a 96 foot thick covered interval which is underlain by dark gray (N3), barren to sparsely fossiliferous mudstone (based on trenching); these interbedded mudstones and packstones are, therefore, taken as the base of this tongue.

The lower packstones in this 84 foot thick sequence are poorly washed biosparites containing a predominantly echinoid- and brachiopod-rich faunal assemblage. Echinoids outnumber brachiopods by two-to-one, and consist of a diverse collection of plates, ossicles, spines, and partial stems. Broken fenestrate and cryptostome(?) bryozoans are also common. Subordinate bioclasts include disarticulated ostracodes, whole gastropods, broken palecypods, foraminifera, conodonts or fish debris, and rare red (coralline?) algae fragments. Size sorting of the bioclasts is good and most are oriented subparallel to bedding. Little evidence of abrasion is present and many are peripherally bored and micritized. Slight size variations occur across thin, irregular micrite-rich seams which cut through the packstones. A vague pelletal texture is apparent throughout the micritic matrix, and small, irregular, micrite-rich intraclast are locally present. Isolated horizontal burrows also occur, but evidence of bioturbation is variable.

The predominant, interbedded fossiliferous mudstones are spicular, in contrast to the packstones, but also contain abundant pelmatazoan and brachiopod fragments, and articulated and disarticulated ostracodes. Fenestrate bryozoan fragments, foraminifera, and conodont fragments are also present. A few of these lime mudstone beds are also laminated, although the majority lack laminae and have a swirled (bioturbated) texture.

To the northeast, at Clover Divide the packstones are largely replaced by fossiliferous wackestones. In contrast to the abundant fossiliferous mudstones at Red Rock River, however, fossiliferous wackestones outnumber these beds here.

Tongue VIS

This tongue is the southwestern extension of the upper half of the major tongue discribed previously. Fossiliferous wackestones and subordinate sparsely fossiliferous wackestones are interbedded with fossiliferous lime mudstones throughout this tongue at Red Rock River. A 25 foot thick sequence of very resistant, thin- to thick-bedded, fossiliferous packstone ledges crop out at the top of the tongue here.

The wackestones consist exclusively of sparse and packed biomicrites and biopelmicrites. No biosparites are recognized in this part of the tongue. As in the wackestones elsewhere in this lithofacies, echinoid and brachiopod debris is omnipresent and generally predominate. Fenestrate and subordinate ramose bryozoan fragments are also common in these beds. Additional faunal elements include ostracodes, pelecypods, gastropods, sponge spicules, and conodont fragments.

Several Late Mississippian brachiopods and corals occur in the fossiliferous wackestones in the lower and middle part of this tongue. The corals, Siphonophyllia sp. and Siphonophyllia excentrica Meek, are diagnostic of Sando Coral Zone V (Chesterian) deposition (W. J. Sando, written communication, 1985). The brachiopods are also diagnostic of Chesterian deposition (Foraminifera Zone 16, 17, and lower part of 18); these include Chonetes sp., Ovatia cf. O. muralis Easton, and Neospirifer praenuntius (J. T. Dutro, written communication, 1985). Several specimens of the palecypod, Limipectin cf. L. otterensis Easton, also occur at the base of this tongue in a sparsely fossiliferous wackestone bed (identification by J. T. Dutro, Jr., 1985).

Many of the bioclasts are randomly oriented and distributed, scarcely abraded, and display partial to complete micritic envelopes. Size sorting of the bioclasts varies from poor to good, although the more fossiliferous beds tend to be better sorted overall. Swirled micritic matrix textures, "dirty" sparry calcite patches, and/or differential neomorphism are present in the majority of the wackestone beds, suggesting reworking of the sediment by an abundant benthic fauna. Burrows are less common and are chiefly horizontal to inclined.

The interbedded fossiliferous lime mudstones contain more sponge spicules and ostracodes than the wackestones, but also contain most of the biotic elements found in the latter beds, as well. Size sorting is characteristically poor and most of the bioclasts are oriented either parallel or subparallel to bedding.

The uppermost fossiliferous packstone beds (packed biomicrites) lack the sponge spicules found in the wackestones, and contain a faunal assemblage dominated by ramose trepostome bryozoans and subordinate fenestrate and cryptostome bryozoans (fig. 37). Unmicritized foraminifers are very common also, in addition to the usual assortment of echinoid and brachiopod debris. Encrusting bryozoans, which display excellent preservation of the cystose (vascular) tissue, are also present (fig. 38). Isolated peloids occur locally, but compose no more than two percent of the rock. Several small specimens of Siphonophyllia sp. occur in the uppermost packstone ledge.

The upper part of this tongue consists of approximately 42 feet of cover which is underlain primarily by barren(?), silty lime mudstone. This covered interval passes vertically into a very thick covered interval characterized by yellowish orange (10 YR 7/6) soil and scattered sandstone float. The shale lithofacies which overlies this tongue elsewhere in the thesis area is not present here, either as a result of a significant change in the depositional environment in this area, or late- or post-Lombard, pre-Amsden uplift and erosion in this area.

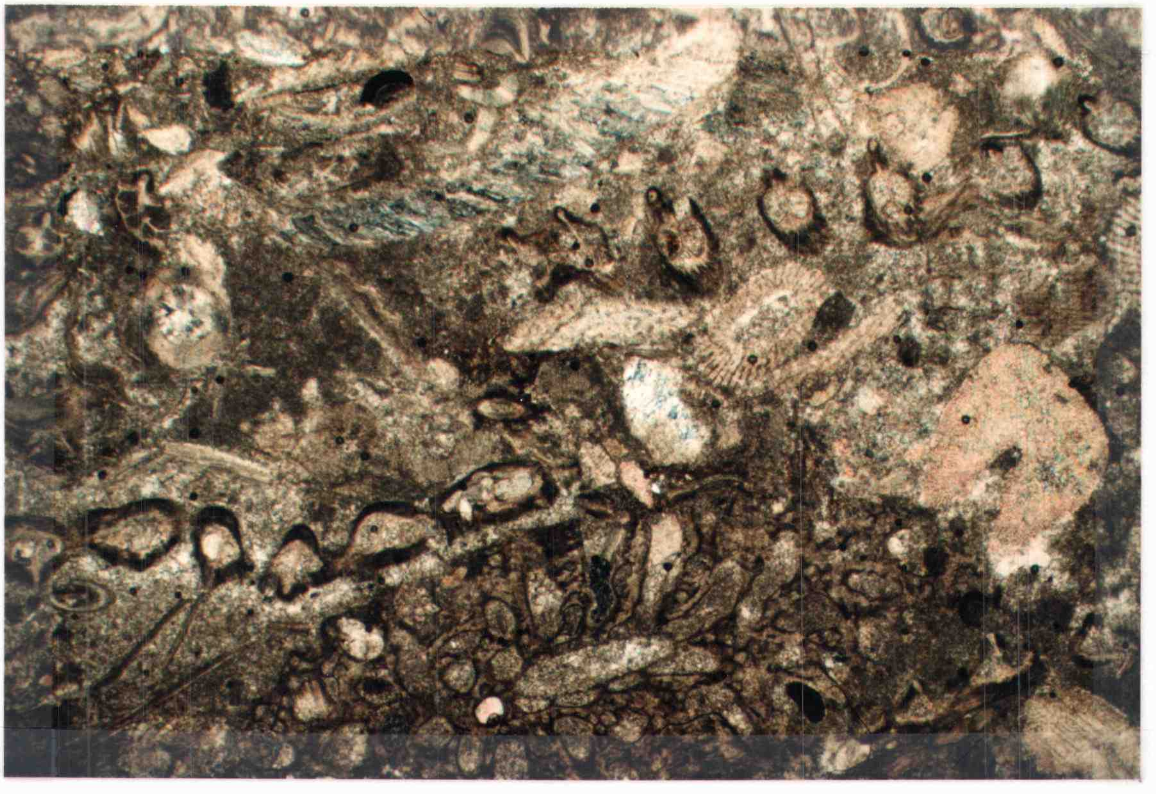


Figure 37. Photomicrograph of packed biomicrite. Note abundant well preserved fenestrate bryozoan fronds and ramose trepostome bryozoans. Abraded echinoid and brachiopod debris also common. Unit 109, Red Rock River section. Crossed nicols.

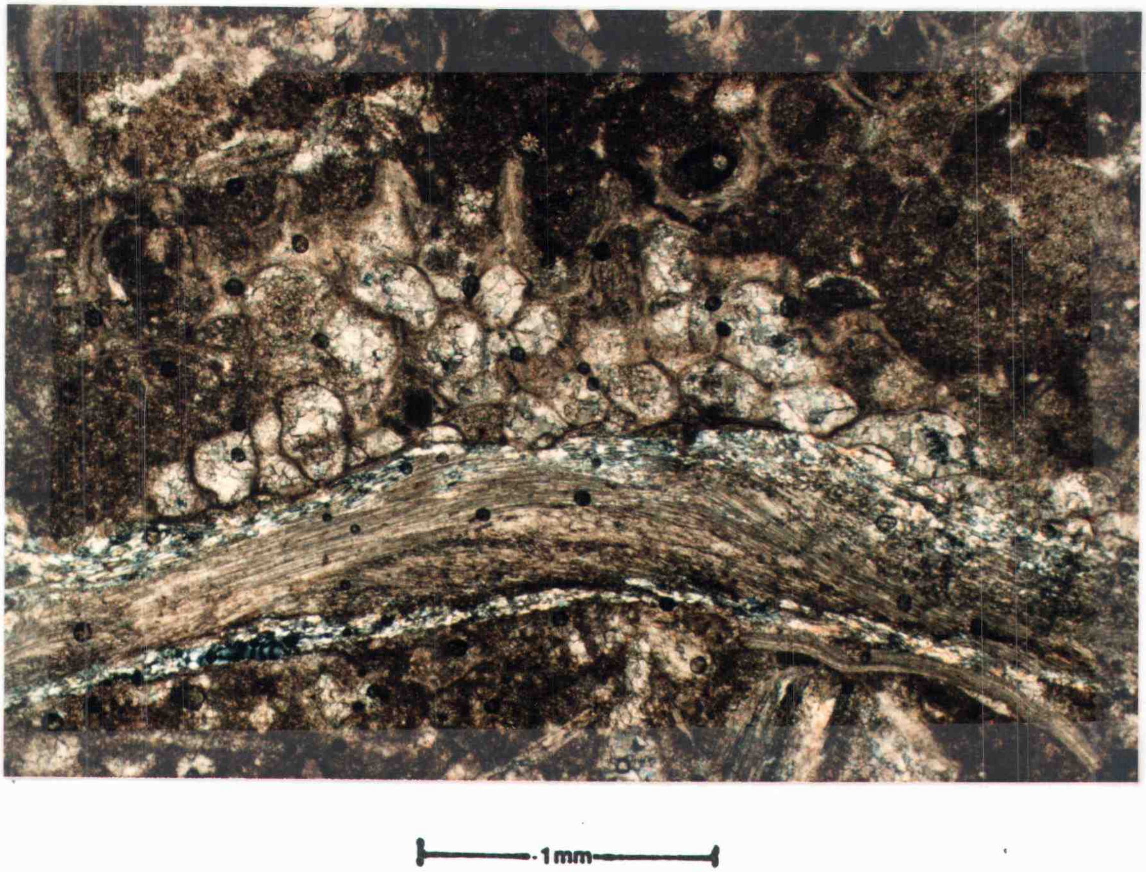


Figure 38. Encrusting bryozoan on partially silicified, impunctate brachiopod valve. Unit 82, Red Rock River section. Crossed nicols.

Clover Meadow section

A thin series of cliffs crop out in the north-central Gravelly Range (SW 1/4, NE 1/4, section 16, T. 9 S., R. 2 W.), which previous workers have mapped as Mission Canyon Limestone or Amsden Formation (Hadley, 1969). Petrographic analysis and several coral collections, however, reveal that the rocks exposed in this cliff sequence are actually of Lombard Limestone affinity. The Lombard is exposed here, at Clover Meadow, as two thin cliff sequences which are herein attributed to recent, westward-directed gravity sliding along intra-Lombard planes of failure (probably bedding planes) and/or along the Kibbey-Lombard transition. The lower cliff and upper cliff sequences are separated by a gentle, hummocky slope, which displays evidence of recent movement, such as deeply cracked ground, and a few small, toppled and precariously oriented trees. The total Lombard section exposed here is only 183.5 feet thick.

Faulting associated with the gravity sliding may have removed some of the Lombard section locally, although the amount of dip separation represented by the hummocky covered interval between the two cliff exposures is unknown. Several discontinuous, massive, thick-bedded sucrosic dolomite beds crop out near the top of the upper cliff sequence and are herein interpreted as the basal Conover Ranch Formation (fig. 39). Several poorly exposed and thin-bedded siltstones and silty sandstones also crop out farther up the hill, above the basal dolomite beds. The lower cliff contains several coralliferous horizons and intervals which contain

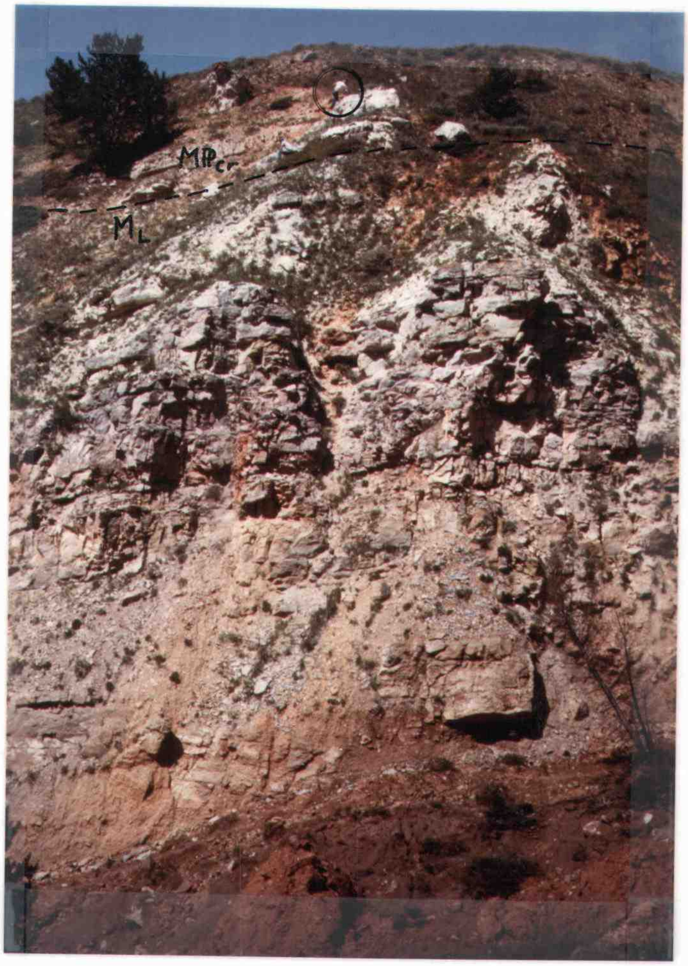


Figure 39. Lombard Limestone exposed in west-facing upper cliffs at Clover Meadow, north-central Gravelly Range (SW 1/4, NE 1/4, section 16, T. 9 S., R. 2 W.). Black line demarcates inferred Lombard Limestone (Ml)-Conover Ranch Formation (MPcr) contact. People near top of hill for scale (see circle).

Siphonophyllia sp. and _Amplexizaphrentis_ sp., which are diagnostic of Coral Zone V (Chesterian) deposition (fig. 40). Most of the _Siphonophyllia_ sp. corals recovered here are small, but the _Amplexizaphrentis_ sp. corals are typically large. The rocks exposed in both cliffs have a microscopic texture and faunal assemblage very similar to that found in the fossiliferous wackestone-packstone lithofacies of the Lombard in the Snowcrest Range. Owing to the thickness of this macrofossil-rich wackestone and subordinate packstone interval, it is tentatively correlated to the major fossiliferous wackestone-packstone tongue (IVS-VIS) in the Snowcrest Range. A more complete discussion of the faulting and inferred relationship of the cliff sequences can be found in Appendix A.

The lower cliff sequence consists of massive, thick- to very thick-bedded fossiliferous wackestones and packstones (sparse and packed biomicrites and biopelmicrites; fig. 41). Microscopic examination indicates that the chief faunal constituents are disarticulated and broken echinoid and brachiopod debris. Secondary taxa include fenestrate and ramose bryozoans, foraminifers, solitary rugose corals, ostracodes, trilobites, and sponge spicules. Sorting varies from poor to good, although the majority of the bioclasts are poorly to moderately sorted by size. Very few of the bioclasts display any evidence of abrasion. Micritic envelopes occur locally. Most of the fossils are randomly oriented, but several intervals contain fossils which lie parallel or subparallel to bedding. Bioturbation is evident in most of the biomicrites and biopelmicrites. Discrete horizontal burrows are also

Figure 40. Two specimens of Siphonophyllia sp. collected in Lombard Limestone in lower cliff sequence (unit 4) at Clover Meadow, north-central Gravelly Range. Scale in centimeters.

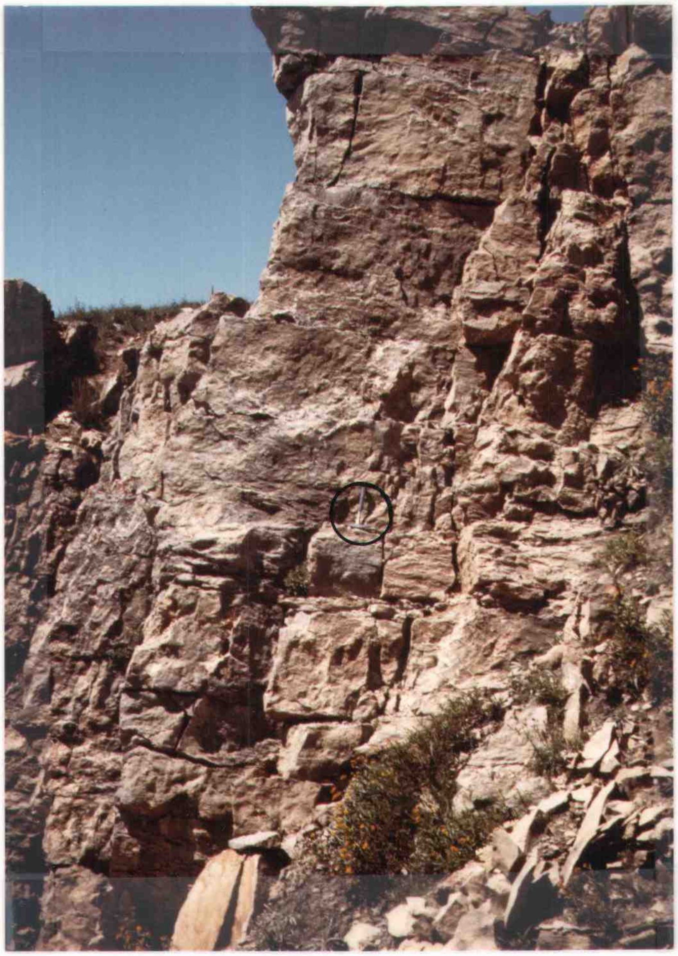


Figure 41. Lombard Limestone exposed in lower cliffs at Clover Meadow, north-central Gravelly Range (SW 1/4, NE 1/4, section 16, T. 9 S., R. 2 W.). Note massive, thick and very thick beds. Hammer in center of photograph for scale (see circle).

common.

Three thick, sparsely fossiliferous wackestone beds crop out 23 feet above the base of the lower cliff sequence, which contain abundant calcareous sponge spicules, foraminifers, and fenestrate and ramose trepostome bryozoan debris. The upper part of this cliff contains a series of biopelmicrites which consist of 25 percent bioclasts and 27 percent peloids. The bioclasts are locally clustered and in grain support, and much of the micritic matrix has a local, relict pelletal texture which suggests reworking of the sediment by an abundant benthic epifauna and infauna. Very fine, scattered, subhedral dolomite rhombs locally compose three percent of the rock.

The upper cliff sequence consists of sparse biomicrites separated by an indeterminate interval of dolomicrites and dolobiomicrites (fig. 39). The faunal assemblage is almost identicle to that in the wackestones and packstones in the lower cliff sequence, except that corals are absent. Pelecypods, foraminifers, and trilobites are all locally abundant, but tend to comprise the subordiante fraction of the assmblage in most of the beds. Peloids are rare, although micritization, extensive reworking by an active benthic infauna, and/or burial processes may have destroyed these allochems. Peripheral to complete micritization of the bioclasts is additionally very common in the lowermost fossiliferous wackestones (sparse biomicrites).

The lower-middle part of this upper cliff sequence is dolomitic. Finely crystalline, mosaic to subhedral rhombic dolomite composes up to 30 percent of the total constituents, locally making up 70 percent in a thin dolomicrite at the top of this dolomitic interval. Most of the rhombs are limpid, but a few are zoned, suggesting multiple growth episodes. Some additionally exhibit a calcite nucleus. Fine to coarse silt accounts for approximately five percent of the rock, but rapidly increases in abundance to ten percent of the total constituents in the capping dolomicrite beds. In contrast to the underlying and overlying beds, bryozoans are rare to absent in the dolomitic interval and ostracodes are more abundant. Isoloated, scarce sponge spicules are the only bioclastic element in the dolomicrite beds.

Most of the bioclast in the beds exposed in the upper cliff sequence are unabraded and randomly oriented. horizontal burrows are present, but most have been obliterated by excessive bioturbation which has generated a swirled, patchy, and/or monotonous reworked texture throughout the rocks. The uppermost beds are deeply weathered, sparse biomicrites containing a predominately silicified bioclast assemblage of pelmatazoan and brachiopod fragments, and subordinate sponge spicules, ostracodes, pelecypods, and gastropods. Quartz silt is minor, composing only two percent of the total constituents. Phosphatic pellets locally make up four percent of the total constituents in these uppermost beds. Unlike the rounded phosphatic pellets found at discrete levels within the Lombard to the west, however, the irregular and locally diffuse edges on these pellets suggest an authigenic origin.

The contact with the overlying, white, sucrosic Conover Ranch dolostones is covered by talus and/or dense vegetation, but appears to be sharp (fig. 39). No angular or undulatory relationships are recognized, although the sharp lithologic change suggests the presence of a disconformity or a rapid change in depositional environment.

Summary

All six fossiliferous wackestone-packstone lithofacies tongues which can be recognized in the study area display similar faunal and textural characteristics which distinguish them from the alternating lime mudstone lithofacies tongues; these criteria are listed on Table 1, which compares and contrasts the two lithofacies. Several major lateral and vertical trends are recognized within this Lombard lithofacies, however, which overprint the variations present in the individual tongues and correlative units in the major tongue to the northeast. These trends include the: (1) increase in abundance of packstones upsection and to the southwest, (2) increase in thickness and lateral continuity of the packstone beds upsection, (3) rapidly decreasing abundance of sponge spicules, (4) increase in abundance of bryozoans to a position of dominance in the faunal assemblage both to the southwest and upsection, and (5) the increase in abundance of deposits indicative of very shallow and/or agitated water conditions upsection.

Characteristic	Lithofacies: Lime mudstone	Lithofacies: Fossiliferous wackestone-packstone
Major lithofacies (Dunham, 1962)	Barren to fossiliferous lime mudstone, sparsely fossiliferous wackestone	Fossiliferous wackestone, fossiliferous packstone, fossiliferous grainstone
Major microfacies (Folk, 1962)	Fossiliferous micrite, sparse biomicrite, sparse biopelmicrite	Sparse/packed biomicrite, packed biopelmicrite and biopelsparite, packed biosparite
Major taxa	Sponge spicules, ostracodes	Echinoids, brachiopods, bryozoans
Minor taxa	Pelecypods, gastropods, echinoids, brachiopods, calcispheres, conodonts	Foraminifera, corals, trilobites, gastropods, nautiloids, ostracodes, conodonts, algae, sponge spicules
Laminites	Moderately common	Rare to absent
Bioturbation	Common	Very common
Burrows	All orientations; most horizontal to inclined	Horizontal to inclined; some dendroid
Peloids	Locally abundant	Locally abundant
Ooliths	Absent	Rare to scarce
Bioclasts: Size sorting	Poor	Poor to excellent
Orientation	Variable; many parallel to bedding	Random
Abrasion	Absent	Absent to common
Micritic envelopes	Rare to absent	Moderately common
Color (fresh)	Black to grayish black	Dark olive gray to brownish gray
Chert nodules and stringers	Common	Rare; locally abundant
Petroliferous odor	Strong to very strong	Weak to strong

Table 1. Textural and faunal characteristics of lime mudstone and fossiliferous wackestone-packstone lithofacies.

Calcareous shale lithofacies

The calcareous shale lithofacies is persistent throughout most of the Snowcrest Range. It is particularly well exposed at Sawtooth, Hogback, and Sliderock Mountains, where thicknesses of 42, 77, and 55 feet, respectively, crop out as ledges and cliffs. Elsewhere in the range this lithofacies is covered, forming gentle to moderate, grassy slopes. Fine shale float can typically be found in the dark colored soil on the grassy slopes, suggesting an underlying shale lithology. On the west and northwest sides of Sawtooth Mountain this unit can be traced for almost one mile, and discontinuous ledges of shale can be found along the entire east flank of Sliderock Mountain.

The cliff-forming habit of these limy shales is restricted to the uppermost part of the unit, exposed on the north side of Sawtooth Mountain. This passes downward and laterally (to the southwest) into the discontinuous ledges which typify this lithofacies throughout the remainder of the range (fig. 42).

The fissile habit of these black (N1) to olive black (5 Y 2/1), silty, calcareous shales varies laterally, passing both vertically and laterally into a planar to slightly undulatory, laminated to flaggy habit. The entire unit characteristically weathers to a light gray (N7) to yellowish gray (5 Y 8/1) color. Very thin to medium bedding is suggested by abrupt vertical variations in splitting habit, and where the fissile splitting habit is absent these rocks are more correctly classified as silty lime mudstones (Dunham, 1962). Laminations are absent in most of the

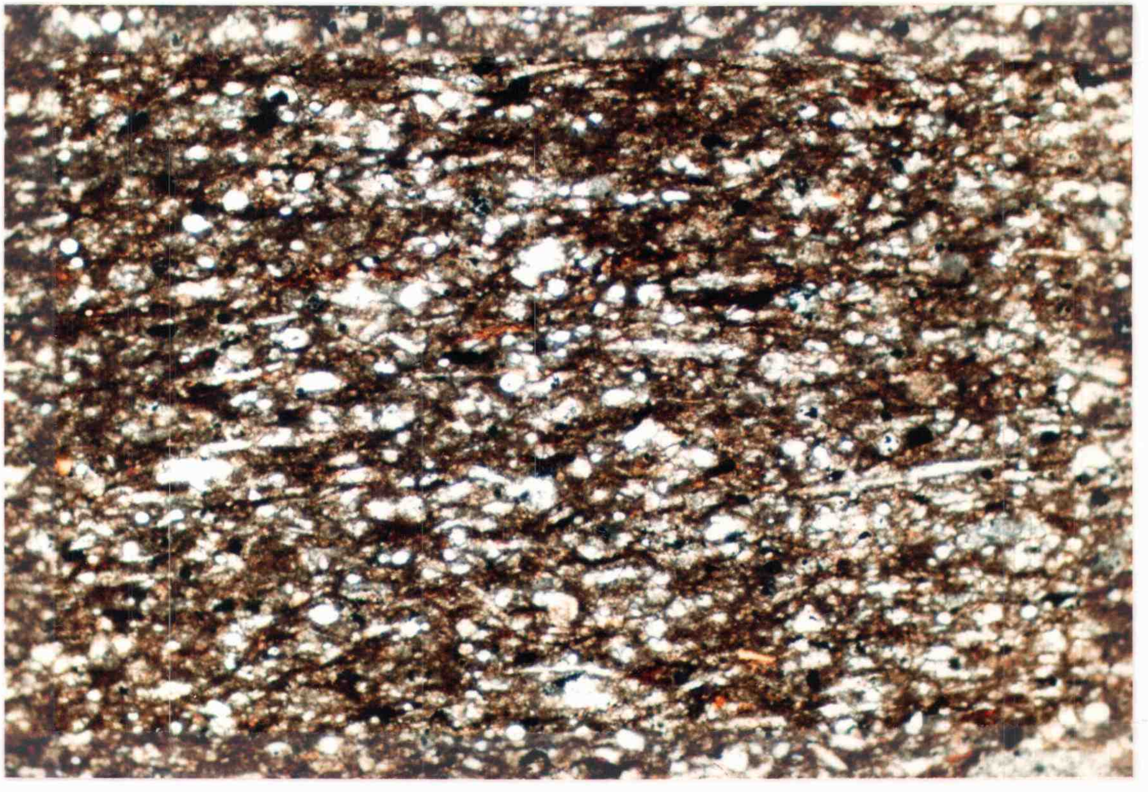
Figure 42. Calcareous shale outcrop in large gully at base of dip slope of hill (9,566') west of Sawtooth Mountain (W 1/2, SW 1/4, section 8, T. 12 S., R. 5 W.).

shale sequence at Sliderock Mountain, but are common in exposures to the southwest. Laminae vary in thickness from 3/32 inch (thin) to 7/16 inch (thick), averaging 3/16 inch thick, and are predominantly planar. Locally, individual lamina and/or sets of laminae are slightly undulatory to disrupted, displaying a pinching and swelling habit; features similar to flame structures are rarely found in the laminated to flaggy beds. Many laminae are characterized by faint variations in color on the weathered surface, possibly in response to the variable amount of preserved organic matter in the individual lamina. The predominantly fissile splitting habit of this unit, the common laminated character of the non-fissile mudstone intervals, and the relatively high proportion of organic material (incicated by the very strong petroliferous odor), combined with the noteworthy absence of burrows and/or ichnofossils along splitting and bedding planes, are indicative of anoxic conditions, in the depositional basin, at least in the lower part of the water column.

Although these rocks appear monotonous in outcrop throughout the range, petrographic analysis reveals a subtle, diverse character which overprints the major mineralogical similarities. Micrite is the chief constituent of the rock, accounting for an average of 68 percent of the total constituents. Porphyroid neomorphism has locally generated microspar and less commonly psuedospar. Organic matter occurs as a golden yellow to brown stain within the micrite and microspar matrix. In addition, irregular clots and dark brown to black threads anastomose throughout the microfabric. Short, black, horizontally stretched, sigmoidal wisps are also common. In contrast to the Sawtooth and Hogback Mountain shales, those at Sliderock Mountain are found to contain appreciably more visible organic matter and/or residue (as a dark stain)(fig. 43). Geochemical analyses reveal a slightly higher total organic carbon content (by weight percent) in the calcareous shales at Sawtooth Mountain than at Hogback Mountain; no data is available from Sliderock Mountain (see Appendix C).

Simple, straight to very slightly curved, calcareous and subordinate siliceous sponge spicules (monaxons) are present in all of the shale samples analyzed. Calcareous sponge spicules are the only allochems found in the shales at Sawtooth and Sliderock Mountains. A few disarticulated and broken inarticulate brachiopod valves, and broken, recrystallized palecypod(?) valves are also present, however, at Hogback Mountain. No evidence of abrasion is found on any of the bioclasts. An increase in the percentage of allochemical constituents is noted from the southwestern end of the Snowcrest Range to the northern end, as bioclasts make up less than 5 percent of the rock at Sawtooth and Hogback Mountains, in contrast to 30 percent at Sliderock Mountain. In all sections the bioclasts are oriented parallel to bedding.

Quartzose silt and subordinate clays make up the terrigenous fraction of the shale. Monocrystalline quartz dominates over chert, and polycrystalline quartz is absent. Grain size (nominal diameter) varies from 0.01 mm (fine silt) to 0.1 mm (very fine sand), averaging 0.03 mm (coarse silt) at Sawtooth Mountain. Slightly finer average grain sizes, 0.028 mm and 0.025 mm, respectively, occur at Hogback and Sliderock Mountains, and the range of sizes



1 MM

Figure 43. Photomicrograph of calcareous shale (silty spicular micrite). Note abundant organic matter (dark brown and black clots). Orange material is phosphatic(?). Unit 14, Sliderock Mountain II section. Plane polarized light.

is less substantial than those found to the southwest. Angularity of the quartz grains is characteristically high, rarely displaying a subrounded profile, while sphericity values vary greatly. A few quartzose silt grains have subhedral to euhedral, bipyrimidal terminations, suggesting an authigenic origin.

The possible presence of subordinate illitic clay is suggested by the absence of red stain on many cryptocrystalline elements with high birefringence and low to moderate (non-variable) relief. X-ray diffraction analysis failed to substantiate this hypothesis, due to either an insignificant quantity of clay, and/or masking of the illite peaks by the more intense and broader quartz peaks, which occur at similar two-theta values.

Dolomite occurs locally rarely, isolated rhombs which compose up to four percent of the rock; trace amounts of cryptocrystalline dolomite cement are indicated by X-ray diffraction and Alzarin Red staining techniques. Diffractogram peak values indicate a slightly ferroan composition for these dolomitic constituents.

The most significant subordinate elements, with respect to interpretations of depositional environment, are the phosphatic pellets ($<$2 mm diameter) and cement which occur primarily in the shales of the southwestern half of the Snowcrest Range. At the Sawtooth Mountain section many pellets, averaging 0.18 mm in diameter, compose up to 20 modal percent of the rock (fig. 44). The amorphous, golden brown pellets range from spherical and well rounded to very irregular, the larger pellets tending to be more irregular in profile.

Most of the pellets are golden brown in color under plane polarized light, but light golden yellow varieties and all hues between also occur. All of the pellets are isotropic under crossed nicols, although complete extinction of the entire pellet is not common. Most of the pellets have a random, honeycomb-like, phosphatic lattice, with the very few to several intralattice spaces filled with dirty, cryptocrystalline, low-magnesium calcite as in the carbonate matrix surrounding the pellets (fig. 44). A few of the pellets are isotropic throughout. The external boundaries of the pellets are sharp, but some exhibit a thin rind or envelope of dirty, cryptocrystalline calcite, distinct from the enveloping micrite surrounding the pellets. These latter pellets are characteristically 100 percent isotropic, in contrast to those lacking a calcite envelope and typically having the phosphatic honeycomb-like structure. Some of the pellets are alternately externally defined, in part or completely, by an indeterminate dark orange to brownish red material, possibly of organic origin, which surrounds the individual pellets. Where two or more pellets are in contact, a deformed margin is common, suggesting compaction while the pellets were still soft and pliable. A thin, intermediary film of organic material, as just described, is common between the interpenetrating pellets.

At Hogback Mountain all of the phosphatic elements are small and irregular, lacking the well developed spherical habit common in the Sawtooth Mountain shales, and account for only two to three modal percent of the rock. Most of the phosphatic material is of coarse silt size, and an appreciable amount occurs as finely disseminated, cryptocrystalline, intergranular material. Finely

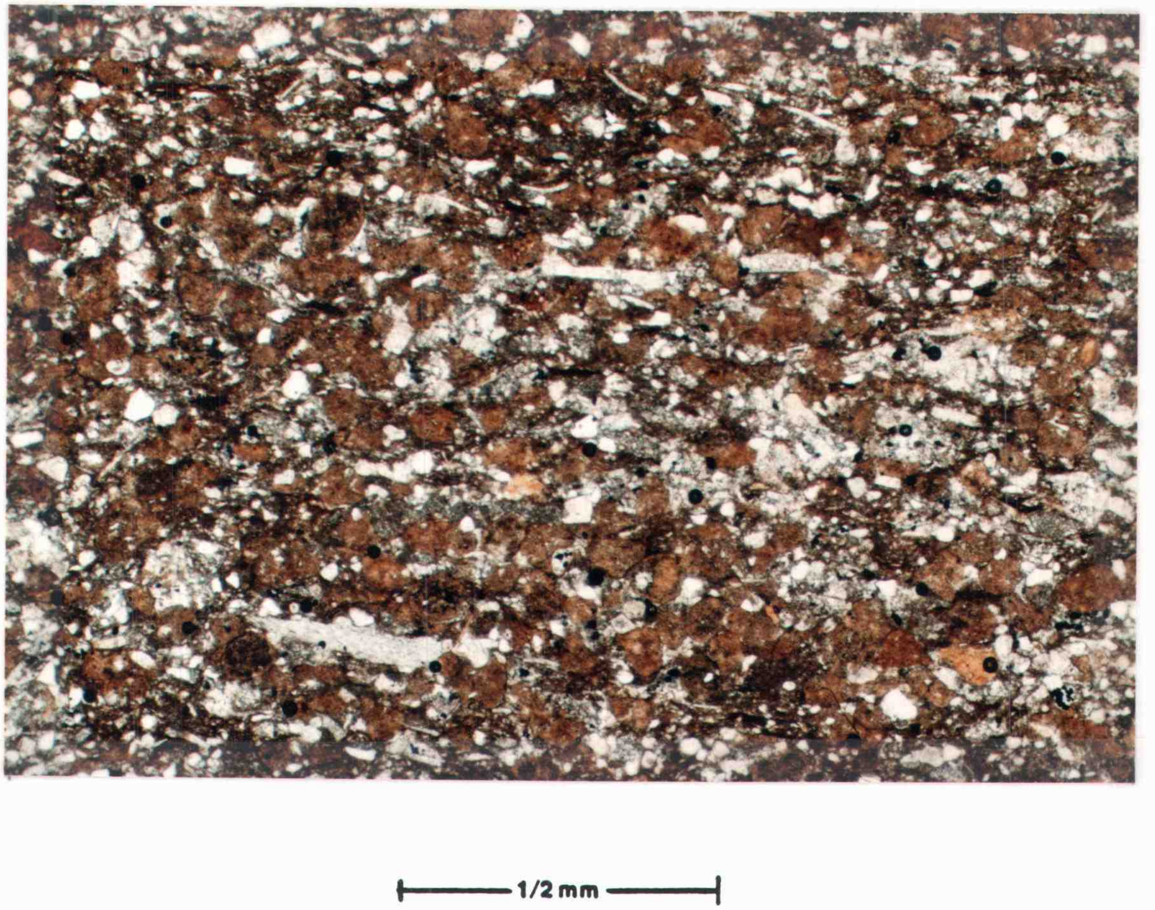


Figure 44. Photomicrograph of phosphatic interval of calcareous shale lithofacies at Sawtooth Mountain. Phosphatic pellets (golden brown) compose approximately 20 percent of the rock. Note concavo-convex boundaries where pellets are in contact. Bioclasts predominantly sponge spicules and disarticulated ostracodes. Unit 55, Sawtooth Mountain section. Plane polarized light.

disseminated, intergranular phosphatic material is also common in the shale at Sawtooth Mountain. X-ray diffraction analysis indicates that the phosphatic material is either fluoroapatite or possibly dahllite. In contrast, the shale at Sliderock Mountain is lacking any phosphatic pellets and appears to have only a minor cryptocrystalline phosphatic cement(?) constituent within the carbonate matrix. A few organic phosphatic elements, such as conodont fragments, however, are present.

Authigenic pyrite is common as small, irregular, opaque masses disseminated throughout the shales. Many pyrite masses are intimately associated with sponge spicules, filling the canal space of the monaxons, and/or situated adjacent to the spicules. Distribution of the pyrite is otherwise non-fabric selective. Most of the masses are of medium to coarse silt size, although some display a botryoidal habit, thereby appearing as large crystal masses.

As previously mentioned, laminations are common, vary in thickness, and are predominantly planar. Subtle variations in the percent of quartzose silt, percent and size of phosphatic pellets, percent and packing density of sponge spicules, crystallinity of the carbonate fraction, and the amount of organic matter and/or organic stain give rise to the laminations commonly observed in thin section. The shales become increasingly non-laminated, in general, to the northeast within the Snowcrest Range.

Combination of the exposed and covered shale intervals, and consideration of the completely covered sections believed to be underlain by shale (based on a preponderance of uncontaminated shale float) reveals that this lithofacies maintains a relatively constant thickness of approximately 148 feet in the nortern half of the range, but thins to a zero thickness edge at the Red Rock River section (SW 1/4, NW 1/4, section 28, T. 13 S., R. 7 W.; see plate 3). The 42 foot thickness at Sawtooth Mountain is a minimum value. The calcareous shale lithofacies crops out in a deep gully on the extreme west-southwest side of Sawtooth Mountain (NW 1/4, SE 1/4, section 8, T. 12 S., R. 5 W.), and the upper part of the unit crops out at the base of a cliff on the north flank of the mountain (NW 1/4, SE 1/4, NE 1/4, section 9, T. 12 S., R. 5 W.). These two exposures are separated by almost one mile and their precise stratigraphic relationship cannot be defined beyond the recognition that they are the same lithofacies. As a result, the thickness given for this interval is that of the shale exposed in section 8, and is considered to be a minimum value. Addition of the two exposed intervals at Sawtooth Mountain falls well below the 148 foot thickness value found to the northeast, although this does not preclude the presence of a thicker section here as the amount of cover between the two exposures is uncertain. The apparent southwestward thinning of this lithofacies in the thesis area, therefore, may not be real.

The absence of this lithofacies at the Red Rock River section is peculiar, and difficult to explain. The uppermost exposed Lombard here consists of several well exposed bryozoan and brachiopod packstone beds interbedded with silty mudstone. These are overlain by a 42 foot thick, gray soil covered interval which grades over five feet into a covered interval characterized by grayish orange to yellowish orange soil and fine sandstone float, interpreted as the basal Conover Ranch lithology. While this Lombard Limestone section is commensurate in thickness with the other Lombard sections in the Snowcrest Range, it is notably incomplete, lacking the calcareous shale and dolomitic lime mudstone lithofacies. It is also interesting to note that this is the thickest Conover Ranch section in the range (Colin Key, personal communication, 1985), although the abrupt change in lithology from a carbonate-dominated to a clastic-dominated sequence supports this interpretation. The lower part of the Conover Ranch is very poorly exposed at this locale and an abrupt lithofacies change to a calcareous sand lithofacies, similar to that capping the Lombard (Big Snowy Formation) to the north-northwest, in the Armstead Anticline area (Hildreth, 1980) is a possibility. The lack of adequate exposure, however, prohibits a definite conclusion regarding this possibility.

Although the calcareous shale lithofacies is a persistent and characteristic unit within the upper part of the Lombard in the Snowcrest Range it is absent to the northwest and southeast, in the Blacktail Mountains and Gravelly Range, respectively. The upper part of the Lombard at these locales is characterized by fossiliferous wackestones and packstones, and non-fossiliferous to fossiliferous mudstones.

Dolomitic lime mudstone lithofacies

The dolomitic lime mudstone lithofacies gradationally overlies the calcareous shale lithofacies, the transition occurring over a three to seven foot interval. This lithofacies can be subdivided into four slightly different mudstone units which vary primarily in bedding habit, percent and type of dolomite, degree of mottling, and color. These four units, from base to top, are: a medium- to thick-bedded, color mottled, dolomitic lime mudstone (unit 1); a thick-bedded, color mottled, slightly dolomitic lime mudstone (unit 2); a thin-bedded lime mudstone (unit 3); and a massive, dolomitic, porphyrotopic lime mudstone (unit 4), disconformably overlain by basal Conover Ranch Formation sandstone (fig. 45).

Unit 1

The basal 19 feet consists of planar, medium- to thick-bedded, color-mottled, dolomitic lime mudstone. Individual beds in this lowermost unit are characterized by a planar to slightly undulatory, laminated to flaggy splitting habit, which grades laterally into locally massive beds. Color mottling is ubiquitous. Individual mottles vary from round to very irregular, and display large variations in size. Olive gray (5 Y 4/1) and yellowish gray (5 Y 7/2) mottles on the surface weather, respectively, from brownish gray (5 YR 4/1) and medium olive gray (5 Y 5/1) mottles, visible on a cut surface. In addition, small (average 1 mm diameter), elliptical, very light gray (N8) mottles are visible on a cut surface and tend to be located within the olive gray mottles, although they

Figure 45. Dolomitic lime mudstone lithofacies exposed in northwest-facing cliffs on northwest flank of Sawtooth Mountain (NW 1/4, SE 1/4, NE 1/4, section 9, T. 12 S., R. 5 W.). Lombard Limestone (Ml)-Conover Ranch Formation (MPcr) contact illustrated by black line near top of cliffs.

cross-cut both the olive gray and brownish gray mottles in places.

Macrofossils are not visible in outcrop and petrographic analysis reveals only a few small objects which may be very poorly preserved calcareous sponge monactines. Quartzose silt, averaging 0.014 mm (fine silt), composes less than one percent of the total constituents. The chief mineralogy of this lime mudstone, in order of abundance, includes dolomite (44 percent), microspar and minor psuedospar (total 30 percent), and ferroan dolomite (26 percent).

The brownish gray mottles are almost entirely dolomitic (64 percent dolomite, 35 percent ferroan dolomite, and approximately one percent pseudospar). Both of the dolomitic constituents occur as limpid, euhedral to predominantly subhedral rhombs in a background of finer, mosaic dolomite. The ferroan dolomite rhombs tend to be larger than the normal dolomite rhombs. The former rhombs average approximately 11 microns in diameter, but attain sizes of 61 microns, while the latter range from 4 to 30 microns, with a mean diameter of 9 microns.

In contrast, the olive gray regions consist of 60 percent dolomite and 40 percent microspar and pseudospar. No ferroan dolomite is found in these mottles. Crystal sizes of the dolomite are similar to those in the brownish gray mottles, but the mosaic microspar displays an average diameter of 10 microns. Bioturbation and/or burrowing is suggested by the patchy character of the microspar and dolomite, and probably acted as the primary factor controlling their distribution. The direct influence of burrowing upon the presence and distribution of color mottling has previously been shown in Ordovician limestones of Saskatchewan and Manitoba by Kendall (1977). Well defined burrows, up to 0.25 mm in diameter are typically dolomite-filled, supporting the hypothesis that the dolomite distribution is controlled by bioturbation and/or burrowing.

At least two generations of fractures cross-cut the mottles. The widest fractures are peripherally filled with coarse, centripetally radiating ferroan dolomite and subordinate normal dolomite, which passes abruptly inward to similar to mosaic, low-magnesium calcite. These fractures are, in turn, cut by thin, calcite-filled fractures.

Small pyrite clusters are common throughout the mudstone, although they tend to aggregate in the brownish gray mottles and are especially common near the margins of these mottles. Many of the pyrite crystals are surrounded by a golden yellow goethite stain, which is probably the result of interaction of the pyrite framboids with groundwater.

Unit 2: Lower part

Gradationally overlying the dolomitic lime mudstone (unit 1) are 41 feet of variably color mottled, slightly dolomitic lime mudstone. Interbedded with the thick, planar mudstone beds are several medium to predominantly thin, silty mudstone beds having a planar to undulatory, laminated to fissile splitting habit. The thick lime mudstone beds locally display planar to slightly undulatory, flaggy to slabby splitting habit.

The lower part of this unit, displaying faint color mottling, is characterized by a pale grayish orange (10 YR 8/4) and pale brown

(5 YR 5/2) color. Etching on a cut surface with dilute hydrochloric acid enhances the faint mottled appearance and reveals mottles having one or more yellowish gray (5 Y 7/2) cores, with an olive gray (5 Y 4/1) peripheral region, set within a light olive gray (5 Y 6/1) background.

In thin section the mottles are found to be composed of a round to elliptical core of finely crystalline, mosaic dolomite which centrifugally grades into much coarser microspar and pseudospar. The peripheral zone appears to have started as a ring of porphyroid neomorphic microspar which expanded, possibly by coalescive neomorphism, into the surrounding calcite-ankerite(?) matrix (fig. 46). Coincident with this neomorphic expansion, the microspar neomorphosed to pseudospar, some crystals attaining diameters of almost 130 microns (0.13 mm). The external margin of the pseudospar halo is very sharp, but the internal boundary is a diffuse zone of porphyroid microspar and pseudospar which centripetally decreases in quantity into the wholly dolomitic core (fig. 46).

The shape of the core versus the peripheral area of the gray mottles provides an important clue to their origin, in addition to their mineralogy. These characteristics suggest that the cores probably represent former burrows excavated into partially lithified micritic mud. Prior to infilling of the burrow by unconsoldated lime mud, neomorphism began in the micrite in the burrow walls, spreading outward as long as groundwater saturated with respect to calcium carbonate continued to circulate through the mud. Sometime after infilling of the burrow, but before lithification was

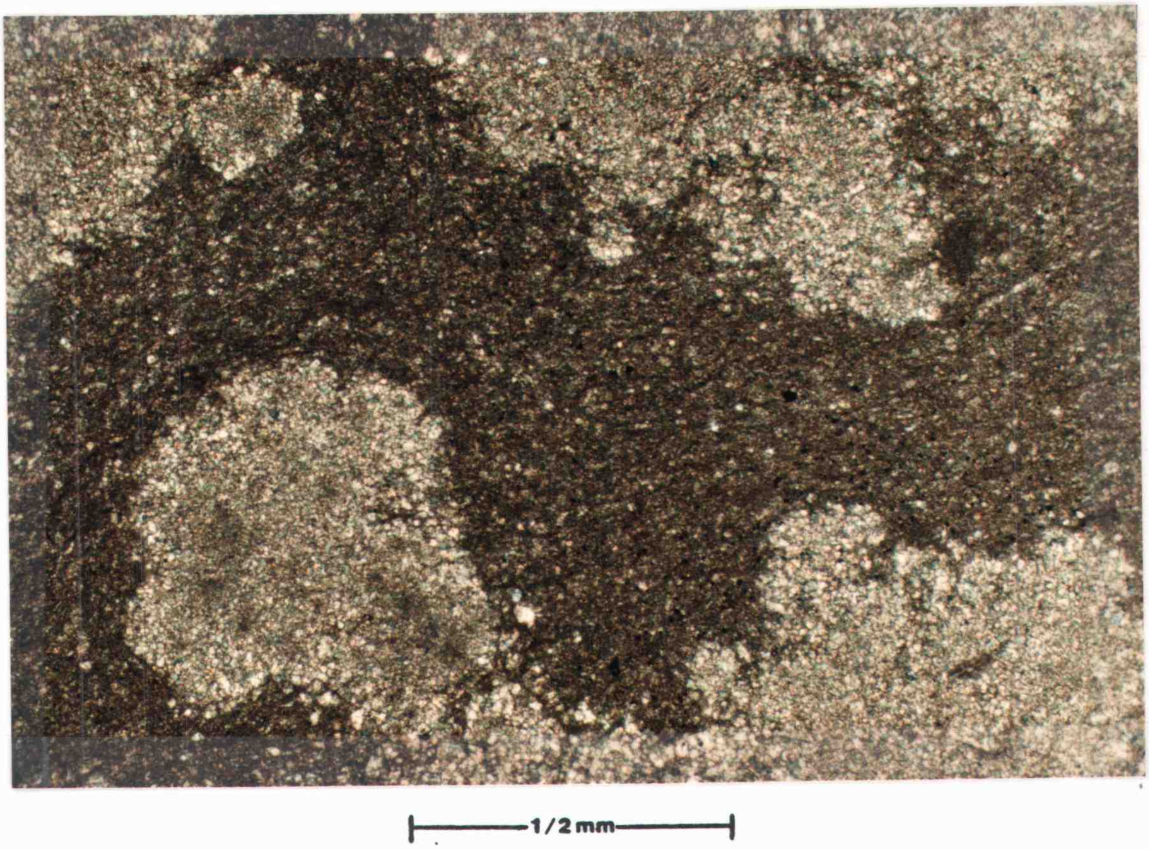


Figure 46. Photomicrograph of mottling in dolomitic lime mudstone. Light colored mottles consist of finely crystalline, mosaic dolomite core area surrounded by coarser grained neomorphic dolomite rim. Brown background composed of microspar and ankerite(?). Quartz silt makes up less than two percent of the total constituents. Unit 57, lower part, Sawtooth Mountain section. Plane polarized light.

complete, the groundwater chemistry changed, dolomitizing the micritic mud in the burrow.

The carbonate mineralogy surrounding the mottles is a monotonous mosaic of finely crystalline calcite and ferroan dolomite (fig. 46); X-ray diffraction analysis indicates that the ferroan dolomite is probably ankerite. Porphyroid neomorphism throughout this region has generated several isolated pseudospar crystals.

A few disarticulated ostracode carapaces and sponge spicules are found in the lighter background. Quartz silt, less than 0.017 mm in diameter (fine to medium silt), makes up approximately two percent of the total constituents. As in the calcareous shale lithofacies, authigenic pyrite is common. The majority of the pyrite occurs within the calcite and ankerite(?), otherwise tending to collect near the outer edges of the mottles. Some of the pyrite crystals are up to 140 microns in diameter. All of the pyrite crystals have very irregular margins, and a few display fine carbonate inclusions, suggesting an authigenic origin for the pyrite.

Unit 2: Upper part

Upsection, the lower part of this unit grades imperceptibly into a microcrystalline, color mottled lime mudstone which megascopically differs from the lime mudstone below only in color. The dark yellowish gray and olive gray mottles below pass upward into dark yellowish orange (10 YR 6/6) mottles set against a dark yellowish brown (10 YR 4/2) background, which weather, respectively, to pale yellowish orange (10 YR 8/6) and pale yellowish brown (10 YR 6/2). Pyrite is notably absent to rare, and fine to coarse quartzose silt composes less than one percent of the rock. Calcareous sponge spicules (monactines), many pseudomorphically replaced by finely crystalline, mosaic dolomite, are much more common, averaging three percent of the total constituents. Ostracode debris is absent. Several irregular patches of coarse, limpid, mosaic calcite occur locally; these may represent recrystallized mollusk fragments or could be infilled burrows.

Calcite predominates in this mudstone, averaging 70 percent of the total constituents, followed by dolomite at 26 percent. Ferrous dolomite within the canals of the monactines occurs in trace amounts, in contrast to the large percentage of ferrous dolomite in the lower part of this unit. Several fractures which cross-cut the upper part of this unit are exclusively filled with ferroan dolomite. A dark brown iron stain defines the walls of the fractures and stains the crystal margins and cleavage traces of the carbonate fracture fill. Smaller, low-magnesium calcite-filled fractures cut these larger fractures.

The mottles display only a moderate mineralogical difference from the main rock mineralogy. The mottles contain slightly more dolomite (56 percent) than calcite (40 percent), in addition to slightly more iron stain. The mottles are poorly defined because of their very diffuse margins, which are characterized by a gradual increase in calcite over dolomite, ultimately acquiring the 72 and 25 percent values, respectively, of the enclosing carbonate matrix.

Despite the subtle difference in mineralogy, the calcite and dolomite in the mottles are slightly coarser than that outside of the mottles. The calcite outside of the mottles is a mixture of micrite and microspar, the microspar occurring in and out of the mottles as fine, limpid, mosaic crystals. The dolomite, on the other hand, occurs chiefly as finely crystalline, limpid, subhedral to euhedral rhombs.

Although pyrite is less common in the upper part of the unit, many of the crystals here appear to be intimately related to the ubiquitous iron stain which probably causes the orangish brown color of the rock. A few of the pyrite crystals are surrounded by a thin halo of golden brown iron stain, which is probably goethite or limonite.

Unit 3

Near the top of this lithofacies the thick beds rapidly change to thin, parallel to predominantly non-parallel, beds of dark yellowish brown (10 YR 4/2) lime mudstone, separated by very thin calcareous shale partings. The non-rhythmic, undulatory character of the top of many of the beds, averaging 1/2 inch of relief, is suggestive of ripples, although no fine-scale cross-bedding is present to substantiate this supposition. The beds, totalling six feet thick, are all massive, lack macrofossils, and weather to a light olive gray (5 Y 6/1) to light gray (N7) color.

Many of the beds pinch and swell, averaging four to five inches in thicknesses. A few beds display an interlocking habit akin to pieces of a jigsaw puzzle. The thin calcareous shale partings between the beds vary in thickness and continuity. Small chert stringers and nodules, typically elongate parallel to bedding, are common.

Dolomite is rare, occurring as very small, poorly developed rhombs which make up three percent of the rock. Ferroan dolomite is found only in trace amounts. Micrite and microspar compose 86 percent of the rock. Fine to medium quartzose silt compose a slim one percent of the rock; most is subrounded to rounded, in contrast to the predominantly subangular to angular habit of the silt in the lower 60 feet of this lithofacies. A few chert grains are found intermixed with the dominant monocrystalline quartz.

In contrast to the nearly non-fossiliferous character of the underlying two units, bioclasts compose almost ten percent of the this rock. Calcareous sponge spicules dominate. In addition to monaxons, a few well preserved foraminifers and disarticulated ostracode carapaces are present. Several very small, round, solid bodies of calcite also are common. These may be calcispheres, but more likely, are monactines lacking the common central canal. Additionally, several smaller (21 micron diameter), porous(?), translucent, orangish yellow objects may be well preserved pollen spores. None of the bioclasts show signs of abrasion and all are oriented parallel to bedding.

Laminations are not visible in outcrop, but many subtle microtextural variations are evident in thin section. The laminations, which are visible in thin section are chiefly parallel and planar, and chiefly differ in crystallinity and abundance of allochemical constituents. Moderately densely packed spicular micrite laminae alternate with microspar-rich laminae with rare, irregular patches of micrite and fewer sponge spicules. The monactines in the latter lamina tend to be more poorly aligned. Quartz silt and pyrite (rare) concentration does not bary between laminae. Individual lamina vary from 0.3 to 5 mm thick, the majority being approximately 2.5 mm thick.

Unit 4

The uppermost unit of this lithofacies is a massive, color mottled dolomitic lime mudstone bed (one foot thick). Vertical fractures create a columnar appearance to the unit. A flaggy habit is locally present. The contact with the underlying lime mudstone is sharp and slightly undulatory. The contact with the overlying basal Amsden sandstone bed is also sharp, but is undulatory and erosional. This contact will be discussed in more detail in a subsequent section.

Moderate brown (5 YR 3/4) and medium light gray (N6) mottles characterize this unit. On a fresh surface these mottles are found to have weathered from moderate brown (5 YR 3/4) and very light olive gray (5 Y 7/1) mottles, respectively. The size and shape of the mottles varies dramatically over a distance of only a few inches. Small whitish mottles, probably representing filled burrows, tend to be concentrated near the gray and orange mottle boundaries.

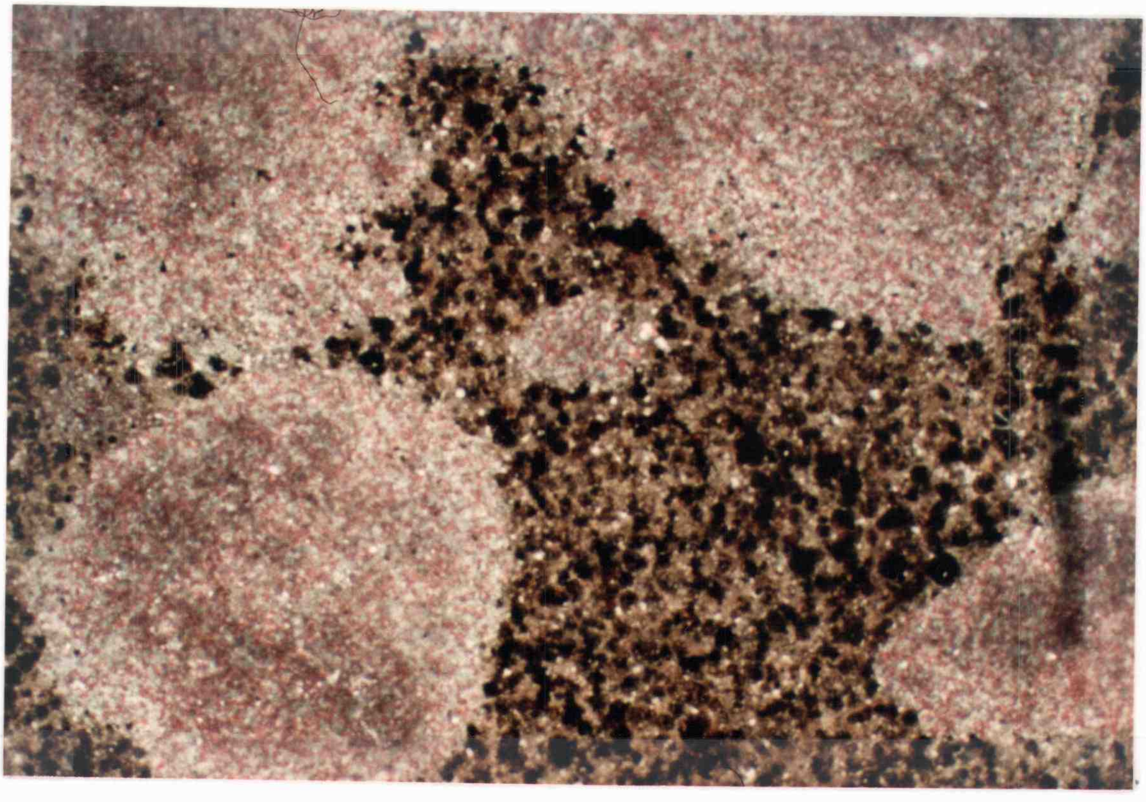
Microscopic analysis reveals that a few randomly oriented calcareous sponge spicules are present in the gray mottles, composing less than one percent of the total rock constituents. The orange mottles typically contain five percent medium silt-size quartz, whereas the the quartz in the gray mottles seldom exceeds one percent and is chiefly fine silt-sized.

Analysis of a cut surface reveals a unique fracture-bound color variation in the orangish mottles. Locally, the orange color abruptly changes to a light olive gray (5 Y 5/2) color across a paper thin fracture. This olive color passes back into the familiar orange color across a second, parallel fracture. No color change occurs in the gray mottles adjacent to the orange/olive mottle transition.

Slight rheological variations additionally distinguish the gray and orange mottles as the thin fractures which pass throughout this unit vary in style within the separate mottles. A given calcite-filled fracture in an orange mottle will abruptly display an anastomosing habit upon passage through a gray mottle; this anastomosing habit ceases and the fracture appears to reunite into one whole fracture again, coincident with the return to an orange mottle.

Mosaic dolomite and low-magnesium calcite (microspar) each compose 50 percent of the gray mottles. Both mineralogies are characterized by a relatively homogeneous grain size, averaging 6 microns, with diameters rarely reaching 23 microns. Both sets of crystals also vary from limpid to slightly cloudy. A few isolated dolomite(?) porphyrotopes, having anomalously large diameters, rarely occur within the gray mottles.

The orange mottles provide a striking contrast to the monotonous gray mottles. Within the orange, very finely crystalline matrix, numerous dolomite(?) porphyrotopes aggregate (fig. 47).



1mm

Figure 47. Photomicrograph of uppermost color-mottled, dolomitic lime mudstone unit (unit 59) at Sawtooth Mountain. Note sharp transition between orangish mottles (porphyrotopic) and gray mottles (stained red by Alzarin Red solution). Note common occurrence of pyrite as nucleus of porphyrotopes. Plane polarized light.

Some of these porphyrotopic crystals have diameters of 220 microns (0.22 mm), and approximately 22 percent of the crystals have a pyrite core. A few crystals are no longer cored by a pyrite crystal (fig. 48); rather, a hematite or limonite ghost of the pyrite remains in its place. Rarely, the pyrite nucleus is gone and finely crystalline carbonate, identical to that of the surrounding matrix, fills the void. The crystals having a pyritic core tend to be anhedral and commonly have a few rings of orangish iron stain. These rings may be growth rings, representing brief periods of growth cessation or a prolonged decrease in the nucleation rate of the crystal, which permitted an iron stain to coat the exterior. At least two to three periods of growth are suggested by these rings. The crystals lacking the pyrite core tend to be missing the rings and are typically subhedral to rarely euhedral.

All of these crystals are characterized by a golden yellow to orangish body color and exhibit iron stained cleavage traces and peripheries. Aside from the few very large crystals, most are very near the average diameter of 71 microns. This suggests that the syn- and/or post-depositional diagenetic microenvironment was relatively stable during the growth of these crystals. Alzarin Red staining indicates a slightly ferroan dolomite composition for the monotonous orange matrix which surrounds the porphyrotopes.

Where the prophyrotopic crystals occur along the sharp boundary between the mottles, two different crystallization habits are noted. Most of the porphyrotopes extend unaltered into the adjacent gray mottle, but a few appear to be truncated at the transition (fig. 48). The reason for this is uncertain.

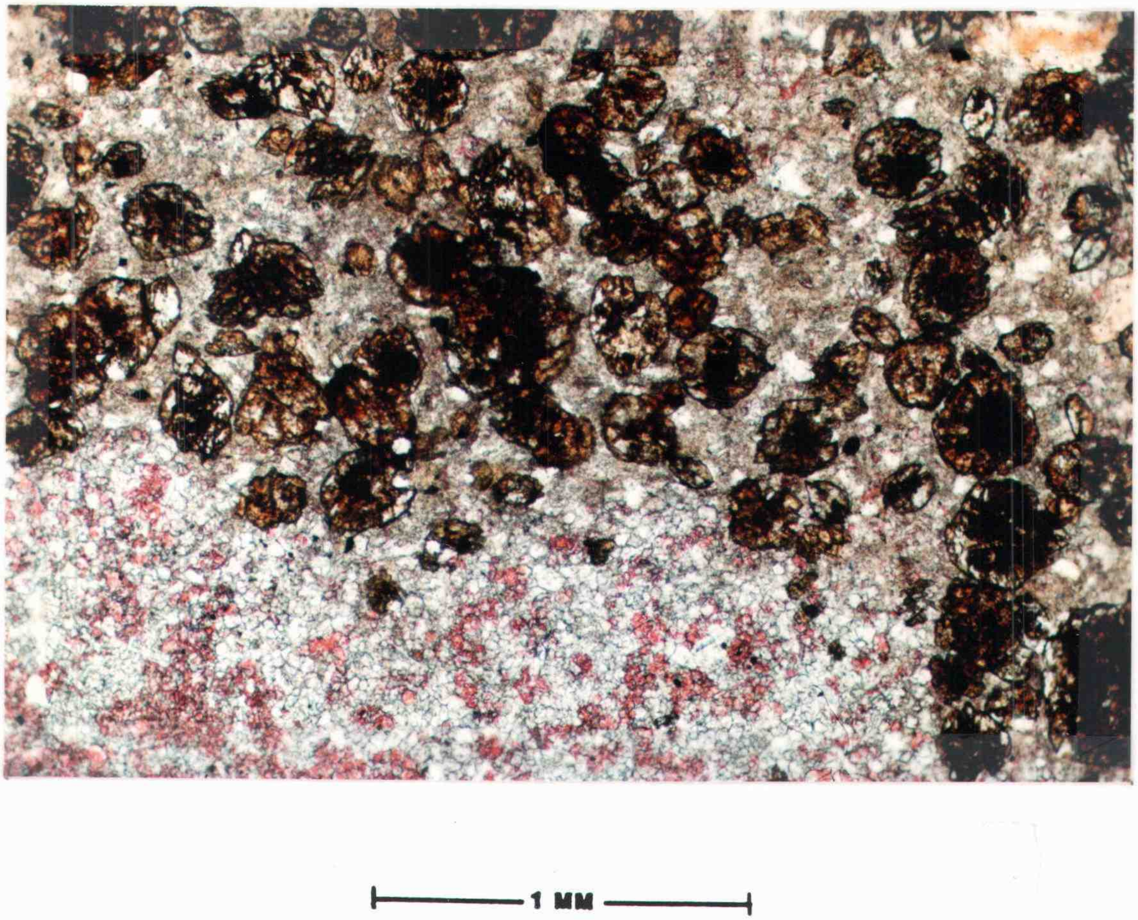


Figure 48. Close-up view (photomicrograph) of transition between gray and orange mottles. Gray mottles composed of 50 percent calcite (stained red) and 50 percent dolomite (white). Note pyrite cores in most dolomite(?) porphyrotopes in orangish mottles. Some porphyrotopes (arrow) display a truncated habit at the transition while others retain crystal habit across transition.

The dolomitic lime mudstone lithofacies is exposed only in a cliff sequence at the head of the west fork of Indian Creek, on the north flank of Sawtooth Mountain (SW 1/4, NE 1/4, section 9, T. 12 S., R. 5 W.). Elsewhere in the Snowcrest Range this lithofacies occurs as a covered, slope-forming interval. Distinction between this lithofacies and the underlying calcareous shale lithofacies in a continuous covered interval is impossible. Any lateral variations in thickness, therefore, can only be suggested where the calcareous shale lithofacies crops out near the identifiable base of the Conover Ranch Formation, and the intervening covered interval can be tentatively regarded as belonging to the dolomitic lime mudstone lithofacies. Based on this approach, this capping Lombard lithofacies is believed to thin to the northeast, possibly thinning to only a few, or zero, feet at Sliderock Mountain (see plate 3). To the west-southwest, this lithofacies is missing, as is the calcareous shale lithofacies, at the Red Rock River section. The reasons for this must be the same as those previously suggested for the calcareous shale lithofacies.

LOMBARD LIMESTONE: DEPOSITIONAL ENVIRONMENT

Introduction

This chapter concentrates on the environment(s) of deposition as interpreted from field and petrographic studies of the rocks in each lithofacies. Integration of the stratigraphic, areal, and temporal relationships of the lithofacies to determine the most likely depositional setting for individual lithofacies is reserved until the regional synthesis in a subsequent chapter.

Lime mudstone lithofacies

The prevalence of fine bioclastic debris (such as sponge spicules, calcispheres, disarticulated ostracodes, and pollen spores(?)) in a micritic matrix, and the general paucity of a shelly fauna are diagnostic of very low to low wave and current agitation, as is the lack of abrasion, poor size sorting, and common orientation of the bioclasts parallel or subparallel to bedding. The dark color of these rocks and the large amount of preserved organic matter, reflected in the strong petroliferous odor and relatively high total organic carbon content, additionally preclude deposition in a shallow, agitated environment.

The source of the small bioclasts may be twofold. Sponges might have been indigenous to the basin, based on the abundance of spicules in most of the sparse biomicrites which characterize this lithofacies. Sponges, however, seldom colonize muddy or silty substrates, like those which characterized this lithotope, but prefer firmer substrates. Thus, the abundant spicular material may have been carried into the thesis area from some external source. Sponge spicules are easily transported in suspension for tens of miles with no evidence of abrasion (J. K. Rigby, personal communication, 1985), so it seems likely that the spicular debris was transported from the platform edge farther west, or from some source within the basin or along the basin margins. Monactine sponge spicules provide little useful information regarding the environment of their origin, unfortunately, since they occur in a variety of environments from hot springs to deep marine settings (deLaubenfels, 1955).

The other predominant bioclasts also are small and readily transported in suspension, permitting an external source. Many of these particles were probably transported into the basin by tidal currents, and periodically by storm currents (Wilson, 1975; Sando, 1976). In contrast to the microfossils, most of the lime mud was probably produced within the basin by the disarticulation or disintegration of red or green algae (Heckel, 1974).

Bioturbated deposits are common throughout the rocks of this lithofacies. Primary evidence of biogenic reworking of the sediment consists of peloids and a relict peloidal texture to the matrix, of burrows, of grazing trails on the bedding planes (including _Helmanthopsis_?), and a patchy or swirled matrix fabric. Although many of these deposits appear to have hosted an abundant benthic infauna, the elongate bioclasts commonly maintain a subparallel aspect with respect to the bedding surface; this suggests that most of the sediment reworking occurred at the sediment-water interface or within the upper few millimeters of the sediment, minimizing disruption of the spicules and other fine bioclasts.

The presence of benthic deposit feeders and grazers, and the noteworthy absence or rarity of shelly macrofossils, suggest that the lower part of the water column in the basin was dysaerobic. Field studies of modern restricted marine basins, such as the Black Sea and the Gulf of California, have shown that marine benthos species diversity, abundance, and body size decrease significantly as the dissolved oxygen content in the water column declines below 1 ml/l (Byers, 1977). In general, the greatest reduction in diversity and abundance occurs in the more heavily calcified epifauna, while soft-bodied infauna, such as polychaetes and nematodes, thrive. It seems likely, therefore, that the presence of bioturbated deposits, and near absence of a shelly fauna in the lime mudstone lithofacies may be explained, in part, by dysaerobic bottom conditions. Ostracodes and subordinate foraminifers and gastropods may have been indigenous to the depositional site as these animals were commonly able to withstand slightly silty environments and dysaerobic conditions, and/or could maintain a position above the muddy bottom (Enos, 1983).

Planar, millimeters-thick laminations are not common in the lime mudstones and sparsely fossiliferous wackestones of this lithofacies, but their occurrence in a few places suggests periodic anaerobic conditions in the depositional environment. These intervals are typically only a few inches thick and may reflect seasonal and/or episodic vertical stratification of the water column. The development of vertical stratification requires some type of hydrographic or physical barrier which restricts or inhibits mixing of the water in the semi-enclosed sea, such as occupied the Snowcrest trough, with that in the open ocean. Vertical mixing by seasonal turnover is generally restricted in hot climates because the surface water seldom cools to a temperature which will promote complete overturn of the water column. The thermocline in some equatorial seas is only 60 feet below sea level (Ettensohn and Elam, 1985). The thermocline in the Lombard sea, therefore, may have been relatively shallow, and/or some type of physical or hydrographic barrier may have existed at these times near the mouth of the Snowcrest trough.

Periodic introduction of terrigenous material is indicated by the intermittent silty lime mudstone intervals. The majority of this detritus is silt-sized and may have been wind-blown from the shoreline or transported in suspension in ebb tidal currents or longshore currents.

Shaly interbeds are common in this lithofacies. Many contain a fossil assemblage similar to that in the lime mudstones, although bioclasts make up a smaller fraction of the total rock. These beds may have been deposited in low areas in the basin floor, or may reflect periods of dysaerobicity in the lower part of the water column. Formation of a well defined pycnocline, probably associated with the thermocline, may have resulted from seasonal climatic fluctuations or with sporadic subsidence locally within the basin which depressed the sea floor below the pycnocline.

All of the preceding features can be produced in either shallow or deep water environments in an epeiric sea. Thin layers with large, disarticulated and broken, and rarely articulated, bioclasts represent deposition from storm events. Gastropods, brachiopods, echinoids, bryozoans, and pelecypods are the most common bioclasts in these storm deposits. Detrital phosphatic pellets also occur locally, signifying upwelling somewhere in the basin or nearby in the miogeosyncline. These thin deposits are relatively common, but do not display well defined periodicity; this may indicate that deposition occurred just below normal wave base, where the wave base associated with moderately energetic storms was sufficient to agitate the unconsolidated sediment. Sedimentation associated with these storm events must have been relatively rapid because laminated lime muds commonly drape and/or envelope the large bioclasts. If the sedimentation rate were slower the deposits would probably be bioturbated. Conversely, these laminae may reflect an entire storm season or series of storms over a given time interval which constantly reworked the sediment, destroying any biogenic structures. The laminations may initially suggest quiet water deposition, but the excellent size sorting of the large bioclasts and textural inversion points to the high energy of the transporting and depositional currents.

Vertical and horizontal stratification, which inhibits colonization of the benthos by a shelly fauna, can also be generated by the development of a salinity gradient. In light of the restricted character of the Snowcrest trough it seems possible that the salinity in the epeiric sea was slightly above normal. Evaporite deposits are not recognized in either the Kibbey or Lombard, however, so the development of dense, hypersaline water which could have migrated seaward along the bottom of the basin seems less probable as an explanation for the near absence of macrofossils than does the dysaerobic model.

Fossiliferous wackestone-packstone lithofacies

The rocks of the fossiliferous wackestone-packstone lithofacies reflect deposition in shallow, sunlit, gently to moderately agitated water. The stalked echinoderms, bryozoans, brachiopods, and corals which characterize this lithofacies are all diagnostic of shallow water environments in the presence of wave and current agitation. Several shallow water corals occur within the packed biomicrites of this lithofacies which are excellent environmental indicators. These corals are generally diagnostic of shallow (less than 50 m), well oxygenated, gently circulating water, within the photic zone. Most favor a firm substrate, clear or relatively free from the rapid accumulation of sediment (Sando, 1980). Several of the solitary rugose corals, however, such as the genus Caninia, were able to root themselves in muddy substrates (J. T. Dutro, Jr., personal communication, 1985). Bryozoans also favor some type of firm substrate, commonly utilizing a shell or some other large skeletal fragment, and generally require silt-free water (Moore et al., 1952).

Several points of evidence, in addition to that provided by the primary taxa, indicate that deposition occurred within or above normal wave base, closer to shore. Sparry calcite is common as both an interparticle cement and intraparticle fill, alluding to the winnowing capacity of the currents in this environment. Size sorting of the bioclasts is generally moderate to excellent, additionally suggesting deposition in a high energy regime. The general absence of abraded margins on the bioclasts, however, indicates that the wave and/or current energy in the depositional environment was not excessive. Large parts of fenestrate bryozoan fronds and partial pelmatazoan stems also are common to these rocks, indicating that wave and current energy was not strong enough to destroy these relatively fragile elements.

Normal wave base in modern epicontinental lagoons and seas varies primarily as a function of the fetch of the trough. Sediments deeper than approximately 25 feet below sea level in Shark Bay, Australia, are rarely subjected to reworking by wave currents. Normal wave base in the Persian Gulf, however, commonly exceeds 60 feet, and is responsible for minor reworking of sediments to depths of 100 feet. The main wind direction in both examples is parallel or subparallel to the trough axis and is from head to mouth. Similar wind patterns are inferred for the Snowcrest trough, so wind-generated waves may have created a well mixed surface zone conducive to extablishment of a shelly fauna to a depth of approximately 100 feet.

Most of the faunal elements in these wackestones, packstones, and grainstones probably lived in or very near the site of deposition. This is particularly true of the corals. Abrasion of many of the large (several inches in diameter) rugose corals collected from the packstone beds was probably the result of in situ water turbulence rather than transportation over long distances along the basin floor (W. J. Sando, written communication, 1985).

Local encrinite accumulations may reflect small crinoid meadows, although deposition in low areas on the basin floor during storm events is also a viable explanation.

Rare to absent quartz in these deposits suggests that terrigenous material was not reaching the basin during periods of fossiliferous wackestone-packstone deposition, or that the Kibbey shoreface was far enough removed to preclude transport of sufficient quantities of clastic material which could inhibit carbonate production. Conversely, moderate wave and current energy carried this material past this shallow water environment into the deeper, quieter parts of the basin.

Sponge spicules and ostracodes are present in many of the fossiliferous limestones, but generally compose a subordinate fraction of the faunal assemblage. Sorting of the bioclasts by size is a pervasive feature in most of the rocks in this lithofacies, as previously mentioned. Strong seaward-directed tidal currents or waves may have winnowed these bioclasts and carried them to the deeper, quieter parts of the basin, leaving behind the denser and/or larger macrofossils. This process may explain the abundance of sponge spicules and ostracodes in the dark lime mudstones to the near exclusion of macrofossils.

The abundant shelly fauna is suggestive of development within the euphotic zone. The combination of a shelly fauna, pervasive bioturbation, light colored deposits, and a low total organic content reflects a well oxygenated environment.

Most of the fossiliferous beds are less than three feet thick and several appear to be discontinuous in outcrop. Others display lateral variation in bioclast abundance. The absence of evidence of in situ mud mound development suggests that most of these fossil accumulations are the result of hydrodynamic processes. The patchy distribution suggested locally by the discontinuous beds may reflect current sorting of the bioclasts into widespread centers of deposition adjacent to centers of erosion. The thin, silty and/or shaly limestone interbeds may reflect episodic or seasonal changes in the basin environment which temporarily inhibited metazoan development, or may represent rapid, lateral migration of the fossiliferous wackestone and packstone lithotope. Similar discontinuous muddy packstones and coralgal grainstones are presently developing in the Persian Gulf on shoals, separated by carbonate mud-filled swales (Wilson and Jordon, 1983). Ooliths and intraclasts occur rarely, but imply that shoals were developing nearby. Such shoaling bodies may be represented by the biosparites which occur here and there in this lithofacies. Many of the biosparites contain an abraded bioclastic assemblage and are well sorted, indicating deposition in a very shallow, high energy environment.

Calcareous shale and dolomitic lime mudstone lithofacies

The transition from fossiliferous packstones, grainstones, and limestone lithoclast conglomerates to black, calcareous shales over an eight-foot-thick interval connotes a radical change in depositional environment. The exclusion of macrofossils, the paucity and lack of diversity of microfossils, and the abundance of bioturbation and burrow structures suggest anoxic benthic conditions (Byers, 1977). The dark color, high total organic carbon content, and common pyrite indicate reducing conditions at and below the sediment-water interface (Berner, 1970).

Shales can reflect sedimentation in shallow or deep water settings. Most restricted shallow water environments, however, such as lagoons, shelves, and bays, typically lack euxinic or organic-rich carbonates (Enos, 1983). In light of the aforementioned attributes of the calcareous shale lithofacies, these rocks probably represent deposition in a deep, vertically stratified basin. Vertical stratification of enclosed or partly enclosed basins is commonly associated with the presence of a well developed pycnocline and/or a sill, restricting horizontal exchange of bottom water with the open ocean. The latter is chiefly related to development .f a thermocline and/or halocline. The thermocline in many modern equatorial seas does not exceed 60 feet below sea level. Thus, the presence of a sill at the mouth of the Snowcrest trough, presence of a shallow thermocline, or a combination of the two may account for the anoxic bottom conditions recorded by the calcareous shales.

Anaerobic conditions can also occur where the oxygen minimum zone intersects the basin floor. An alternative model invoking open connection with the open ocean, therefore, may also explain the origin of these shales.

The origin of the detrital phosphatic pellets in this lithofacies is unknown. Phosphatic pellets suggest nearby upwelling to provide the nutrients necessary for rapid proliferation of planktonic and nektonic carbonate-secreting organisms which ultimately promotes phosphorite precipitation at the sediment-water interface. Phosphorite deposits also have been located in estuarine environments associated with runoff of nutrient-rich freshwater along the Atlantic coastal plain (Pevear, 1966). The low humic kerogen and high sapropelic kerogen content in these shales suggests that freshwater input from rivers was minor (see petroleum potential chapter). Upwelling must have been the chief mechanism promoting nearby phosphorite precipitation. The detrital character of the pellets indicates an origin external to the study area, although the absence of coarse, hydrodynamically equivalent bioclastic material suggests that the source was close.

In addition to the inhibition of metazoans by anoxic bottom conditions, the moderate quartz silt and sand content may have limited establishment of filter feeders, although mollusks, ostracodes, and annelids can all exist in silty water (Heckel, 1972); these are not found in the shales, however. Anaerobicity in the lower part of the water column, therefore, is interpreted as the main factor inhibiting the presence of an infaunal or epifaunal taxa.

The gradational transition to the dolomitic lime mudstone reflects a slow change in the depositional environment. The near absence of bioclasts in the dolomitic lime mudstones signifies continuation of a stressful benthic environment which inhibited establishment of a shelly epifauna. The color mottling which characterizes these rocks, however, reflects a subtle change in the environment which permitted the reintroduction of a benthic infauana. It is apparent that the stratified water column which previously existed broke down or vertical (thermal) mixing slightly increased, causing replacement of the anaerobic bottom conditions by dysaerobic conditions. The slight increase in dissolved oxygen content in the depositional environment is also suggested by the marked color change of the rocks from black and dark gray to light brown.

Slow sedimentation rates may also explain the paucity of bioclastic debris. Long-term exposure at the sediment-water interface allows time for chemical dissolution and/or mechanical breakdown by benthic scavengers.

Many of the mottles appear to display two periods of burrowing. Kendall (1977) has observed similar relationships in color mottled Ordovician dolomites in Canada. Early lithification of the sediment restricted the second generation of burrowing to the unlithified first generation burrows. Such a process may have occurred in the Lombard dolomitic lime mudstones.

The increased oxygen content in the lower part of the water column may be the result of major changes in the basin configuration which promoted a deepening of normal wave base, shallowing of the basin as a whole, and/or decreased restriction across a carbonate sill at the mouth of the trough. Destabilization of the pycnocline may be associated with any of these changes.

The origin of the dolomite is unknown. Evidence of continuous or intermittent subaerial exposure is absent, so seepage reflux on a tidal flat seems unlikely. Development of a meteoric mixing system, however, similar to that proposed to explain the dolomitization of the lower to middle Paleozoic carbonate rocks of the Cordilleran miogeocline of Nevada (Dunham and Olson, 1978) may explain the extensive dolomitization in the uppermost Lombard carbonates. That the dolomite distribution coincides with the burrowing indicates that the burrowing preceded the dolomitization event. The large dolomite porphyrotopes in the uppermost part of this lithofacies (unit 4) suggest a lengthy period of stable physico-chemical conditions conducive to extended growth of the crystal, although the scattered zoned(?) porphyrotopes suggest several periods of instability. The paucity of well zoned porphyrotopes suggests that the times of instability were relatively brief and that moderately stable environmental conditions were the rule.

Reducing conditions in the sediment are indicated by the abundant pyrite at many levels in the lithofacies. The pyrite does not directly indicate negative Eh values in the lower part of the water column, but does suggest that conditions at the sediment-water interface, or just below may have been slightly reducing. Conversely, some of the pyrite may have originated from the same formation fluids which dolomitized the lime mudstones.

Structures and petrographic features diagnostic of deposition on a tidal flat are absent. It seems likely, therefore, that deposition occurred in a moderately deep basin, below wave base and possibly at the lower level of the photic zone.

AGE OF THE LOMBARD LIMESTONE

Early workers correlated the Otter and Heath Formations in the Big Snowy trough to the Big Snowy Formation in southwestern Montana, assigning a Chesterian age to these rocks (Maughan and Roberts, 1967; Roberts, 1979). Recent studies have confirmed that the Lombard Limestone is correlative to the Otter and Heath, but is older than these units in the west and is, therefore, diachronous to the northeast.

Conodont, coral, foraminifera, and brachiopod collections from the Tendoy Mountains, near the Montana-Idaho border, provide a late Meramecian through late Chesterian age for the Lombard (fig. 49; Sando et al., 1985). Conodont collections in the Bridger Range, however, indicate that the Lombard is entirely of early to late Chesterian age (Guthrie, 1984). The lower part of the Lombard in southwesternmost Montana is commonly poorly exposed, precluding the collection of biostratigraphically useful fossils (B. R. Wardlaw, personal communication, 1985). Thus, the more resistant upper part of the Lombard is typically the only source of fossils diagnostic for age in the Lombard. Such is the case in the study area.

Eighty-three collections of corals, brachiopods, bryozoans, and pelecypods from the Lombard were made in the Snowcrest and Gravelly Ranges, and at Sheep Creek Canyon. These collections yielded 21 coral and brachiopod species of which most are specifically diagnostic of Chesterian age (Foraminifera Zone 16i to 18; W. J. Sando and J. T. Dutro, Jr., written communication, 1985);

SOURCES FOR AGES AND RELATIONSHIPS OF UNITS

I: Skipp et al. (1979); Dutro et al. (1984); Stamm (1984); P. E. Isaacson, personal communication, 1985; B. R. Wardlaw, personal communication, 1985; Wardlaw and Pecora (1985)

II: Sando et al. (1975); Brewster (1984); Guthrie (1984); Hadley et al. (1980); C. F. Key, personal communication, 1985; Sando et al. (1985); B. R. Wardlaw, personal communication; Wardlaw and Pecora (1985); This report.

III: Hadley (1950); Sloss and Moritz (1950); Harris (1972); Sando et al. (1975); Davis (1983).

FOSSIL ZONATION:

X: Mamet Foraminiferal Zones (Mamet and Bamber, 1969)

Y: Western United States Megafaunal Zones (Sando, Mamet, and Dutro, 1969)

Z: Sando Coral Zones (Sando and Bamber, 1979)

Figure 49. Time-stratigraphic chart showing (following page) temporal relationships of Late Mississippian units in east-central Idaho, southwestern Montana, and central Montana. Compiled and modified by the author from sources listed above.

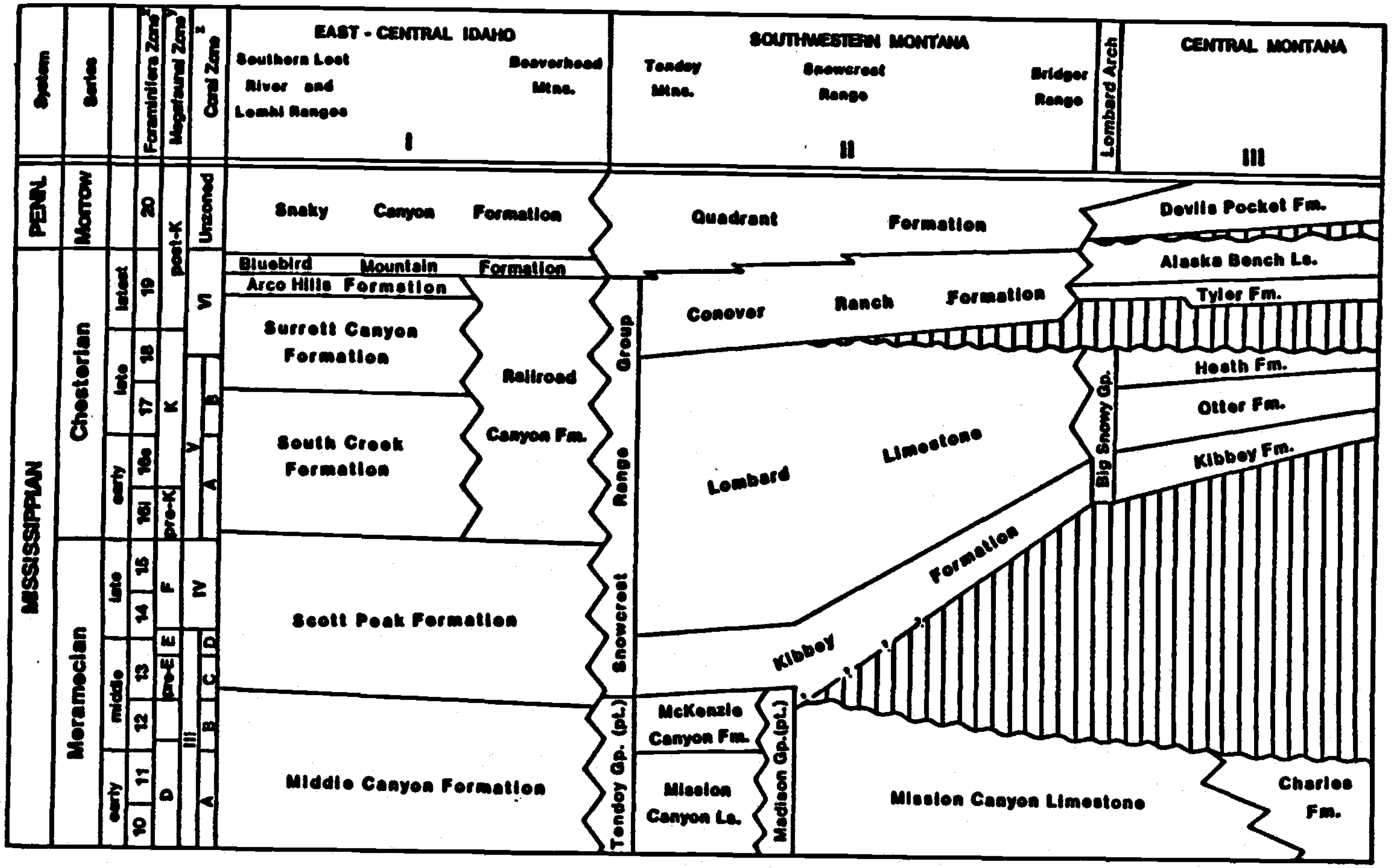


Figure 49 (continued): Data sources and fossil zonation legend shown on previous page.

these collections are listed on Table 2. Two additional corals, diagnostic of Osagean to early Meramecian age, were also identified from a thrust slice(?) of Lodgepole or Mission Canyon Limestone within one Lombard section.

All of the corals collected from the Lombard in the Snowcrest Range occurred in rocks of the fossiliferous wackestone-packstone lithofacies in the upper half of the formation (tongues IVS-VIS). Two of these corals, Siphonophyllia sp. and S. excentrica Meek, are diagnostic for Coral Zone V (early and late Chesterian; Sando and Bamber, 1979). Amplexizaphrentis sp. and Michelinia cf. M. meekana Girty are long-ranging species indicative only of Mississippian time.

Several specimens of the tabulate coral Duncanopora sp. occur in a fossiliferous wackestone bed 37 feet below the top of the Lombard at Sheep Creek Canyon. Three thick, limestone beds crop out approximately 203 feet lower, which contain an abundant assemblage of solitary and colonial rugose corals. "Pseudodorlodotia"? sp. and Multithecapora morphogroup A are present in these beds and are diagnostic of Coral Zone VB and IV to VA, respectively (W. J. Sando, written communication, 1985); these corals correspond, respectively, to late Chesterian and late Meramecian through early Chesterian time.

Fourteen different brachiopod species were identified from the Lombard in the Snowcrest Range (table 2). All of these brachiopods are Chesterian in age, approximately equivalent to Foraminifera Zones 16i through 17 (J. T. Dutro, Jr., written communication, 1985). The lowest identified brachiopod collected in

LIST OF FOSSILS RECOVERED IN LOMBARD LIMESTONE: SNOWCREST, BLACKTAIL, AND GRAVELLY RANGES

Section location	Coral taxa	Unit(s)
Red Rock River	*Siphonophyllia* sp.	82, 84, 111
Clover Divide	*Vesiculophyllum* sp.	Mission Canyon Fm.
	Diphyphyllum sp.	
Sawtooth Mountain	*Amplexizaphrentis* sp.	45
	Siphonophyllia sp.	43, 50
	Michelinia cf. *M. meekana* Girty	50
Hogback Mountain	*Michelinia* cf. *M. meekana* Girty	7
	Siphonophyllia sp.	30
Sliderock Mountain	Dissepimented horn coral, indet.	18 (I)
	Amplexizaphrentis sp.	11 (II)
	Siphonophyllia sp.	11 (II)
	Vesiculophyllum sp.	11 (II)
	Amplexoid coral, indet.	11 (II)
Clover Meadow	*Amplexizaphrentis* large sp.	1
	Siphonophyllia sp.	2, 4
Sheep Creek Canyon	*Duncanopora* sp.	37' below top
	Amplexizaphrentis sp.	47' below top
	Siphonophyllia sp.	203' below top
	Siphonophyllia sp. (semicolonial)	
	"*Pseudodorlodotia*" sp.	"
	Multithecopora morphogroup A	"

	Brachiopod and pelecypod taxa	
Red Rock River	*Ovatia* cf. *O. muralis* Gordon	69
	Limipectin cf. *L. otterensis* Easton	69
	Neospirifer praenuntius Easton	82
	Chonetes sp.?	92

Table 2. List of fossils collected in study area.

LIST OF FOSSILS RECOVERED IN LOMBARD LIMESTONE:
(CONTINUED)

Section	Brachiopod and pelecypod taxa	Unit(s)
Clover Divide	_Antiquatonia_ aff. _A. pernodosa_ Easton	55
	Anthracospirifer curvilateralis Easton	55, float
	Composita sp.	57
	Composita cf. _C. subquadrata_ Hall	float
Sawtooth Mountain	_Spirifer_ cf. _S. brazerianus_	22
	Anthracospirifer curvilateralis Easton	31
	Composita sp.	39, 45
	Antiquatonia aff. _A. pernodosa_ Easton	50
	Inflatia aff. _I. richardsi_ Girty	50
	Anthracospirifer curvialteralis Easton	50
Sliderock Mountain	_Inflatia_ cf. _I. obsoletus_ Easton	18 (I)
	large _Chonetes_ sp.	18 (I)
	Orthotetaceans, indet.	38 (I)
	Antiquatonia sp.	10/11 (II)
	Inflatia cf. _I. obsoletus_ Easton	10/11 (II)
	Inflatia sp.	10/11 (II)
	Flexaria sp.	10/11 (II)
	Diaphragmus cf. _D. centriensis_ Worthen	10/11 (II)
	Anthracospirifer curvilateralis Easton	10/11 (II)
	Composita cf. _C. sulcata_ Weller	10/11 (II)
Snowcrest Mountain	_Inflatia_ sp.?	51
	Inflatia sp.	52
	Spirifer sp. (possibly _S. brazerianus_ Girty)	52
	Antiquatonia? sp.	52

Table 2 (continued).

the Lombard of the Snowcrest Range is a specimen of *Inflatia* cf. *I. obsoletus* Easton, which occurred 210 feet above the base of the Sliderock Mountain I section. Several specimens of *Anthracospirifer* cf. *A. curvilateralis* Easton occur in the upper two-thirds of the Lombard throughout the range. This brachiopod is generally diagnostic of Foraminifera Zone 17 (early late to middle late Chesterian; J. T. Dutro, Jr., written communication, 1985). The majority of the brachiopods collected occurred in the upper half of the Lombard.

The age of the lower half of the Lombard in the study area is uncertain, but can be ascertained by correlating with ages determined for the same interval in adjacent areas. Recent conodont collections in the Basin Creek area (fig. 2), at the southwesternmost extension of the Snowcrest Range have documented a late Meramecian to earliest Chesterian age (Foraminifera Zone 14-16i) for the basal Lombard (B. R. Wardlaw, personal communication, 1985). Northeast of the study area, at Baldy Mountain, the lowest part of the Lombard is covered, but the oldest exposed fossiliferous units yield an early Chesterian age (Hadley et al, 1984; B. R. Wardlaw, personal communication, 1985). Thus, the lower half of the Lombard may be as old as late Meramecian (Foraminifera Zone 14 and 15), but is no younger than earliest Chesterian (Foraminifera Zone 16i, lower part). The base of the Lombard, therefore, is probably also slightly diachronous to the northeast in the study area (fig. 49).

The upper half of the Lombard in the study area is entirely Chesterian based on of the widespread occurrence of corals diagnostic of this age in all tongues above IVS (see plate 3). Chesterian corals also occur in the lower part of the Lombard at the type section locality in the Horseshoe Hills area, near Toston, Montana (B. R. Wardlaw, personal communication, 1985). Thus, the upper half of the Lombard in the Snowcrest Range is correlative with most, if not all, of the Lombard at the northeastern end of the Late Mississippian Snowcrest trough. This confirms the diachronous character of the Lombard Limestone in southwestern Montana.

The age of the uppermost Lombard in the study area is unknown. Several brachiopods, including _Orthotetes kaskaskiensis bransonorum_ Gordon, _Composita_ cf. _C. poposiensis_ Gordon, _Anthracospirifer welleri lincolnensis_ Gordon, _Anthracospirifer_ aff. _A. occiduus_ Sadlick, and _Orbiculoidea_ cf. _O. wyomingensis_ Branson and Greger, were collected from a thick limestone interval in the overlying Conover Ranch in the Snowcrest Range (C. F. Key, written communication, 1985). These brachiopod taxa are diagnostic of late to latest Chesterian time (Foraminifera Zone 18, upper part, to 19). The uppermost, undated calcareous shales and dolomitic lime mudstones, therefore, are probably no younger than late to latest Chesterian (Foraminifera Zone 18 to 19, lowest part) in age (fig. 49). This age corresponds well with that determined for the uppermost Lombard and Heath elsewhere in southwestern and central Montana.

Comparison with Late Mississippian units to the east, south, and west reveal that the Lombard is correlative, respectively, to the Otter and Heath Formations in central Montana (Big Snowy trough); Horseshoe Shale and Moffatt Trail Members of the Amsden Formation in west and west-central Wyoming (Wyoming basin); and Scott Peak (upper half), South Creek, Railroad Canyon, and Surrett Canyon (lower 400 feet) Formations in east-central Idaho (outer cratonic platform) (Easton, 1962; Huh, 1967; Maughan and Roberts, 1967; Mamet et al., 1971; Gordon, 1975; Sando, 1975; Sando et al., 1975; Sando et al., 1985; Wardlaw and Pecora, 1985; J. T. Dutro, Jr., personal communication, 1985). These relationships are diagramatically illustrated on Figure 49.

RELATIONSHIP OF THE LOMBARD LIMESTONE TO THE OVERLYING CONOVER RANCH FORMATION

The Lombard-Conover Ranch contact is poorly exposed throughout most of southwestern and central Montana. Subsurface and scattered surface exposures indicate an unconformable relationship between the correlative Heath and Tyler Formations east of the Lombard arch, in the Big Snowy trough (fig. 9; Harris, 1972; Sando et al., 1975). West of the Lombard arch, in the Bridger Range, the Lombard-Conover Ranch contact is marked by a duracrust (caliche), which signifies an extended period of subaerial exposure prior to Conover Ranch deposition (Guthrie, 1984).

The disconformity recognized in the Bridger Range is extended southwest to Baldy Mountain, but is not recognized southwest of the this area by Hadley and others (1984). In the Tendoy Mountains, conodont and coral data indicate that the Lombard is conformably overlain by the Conover Ranch (Sando et al., 1985). Hildreth (1980, 1981) has also recognized a gradational contact in the Armstead anticline area, characterized by increasingly sandy, packed biomicrites of Conover Ranch affinity.

Owing to the non-resistant character of the calcareous shales and dolomitic lime mudstones of the uppermost Lombard and siltstones and mudstones of the basal Conover Ranch, this contact is very poorly exposed at most localities in the thesis area. An excellent cliff exposure of the contact, however, occurs at Sawtooth Mountain (fig. 2). The transition here occurs as a sharp lithologic break from light gray, color mottled, dolomitic lime mudstone to massive, calcite-cemented quartz arenite (fig. 50). The

Figure 50. Lombard Limestone-Conover Ranch Formation transition exposed in cliff exposure at Sawtooth Mountain (NW 1/4, SE 1/4, NE 1/4, section 9, T. 12 S., R. 5 W.; also see figure 45). Black line demarcates disconformable contact. Black numbers of metal rule occur at one inch increments.

contact is undulatory with at least two inches of relief. Flaggy parting units at the top of the lime mudstone are commonly truncated against the troughs of the undulatory surface, suggesting a period of erosion before or during deposition of the sands (fig. 51). Angular to subrounded lime mudstone rip-up clasts also occur at the base of the sandstone, especially in the troughs. No evidence of caliche development was found along the contact.

An abrupt change in depositional environment across this Lombard-Conover Ranch transition is also evident at Sheep Creek Canyon, although direct superposition of these two units does not occur. A two foot thick, buff, clayey interval separates the limestone lithoclast conglomerates of the basal Conover Ranch from the underlying fossiliferous wackestones and mudstones of the Lombard. This thin, covered interval probably represents post-Lombard, pre-Conover Ranch soil development (E. K. Maughan, personal communication, 1985). The calcareous shales and dolomitic lime mudstones which characterize the the uppermost Lombard in the Snowcrest Range are not present here.

The shales and dolomitic lime mudstones are also absent at the Lombard-Conover Ranch transition at Clover Meadow, in the north-central Gravelly Range (fig. 2). The uppermost Lombard consists of deeply weathered, sparse biomicrites overlain by sucrosic dolomites of the basal Conover Ranch. The contact between these two units is obscured by a thin soil and vegetation interval (fig. 39).

The amount of Lombard Limestone missing at each of these sections is uncertain. The complete absence of calcareous shales

Figure 51. Close-up view of Lombard Limestone-Conover Ranch Formation contact. Note undulatory character of contact and truncation of flaggy parting units in uppermost dolomitic lime mudstones. Approximately two inches of relief occurs along the contact in the left half of the photograph.

and dolomitic lime mudstones at Sheep Creek Canyon and Clover Meadow suggests extensive uplift and erosion preceded Conover Ranch deposition. Major lateral facies changes in the uppermost Lombard may also account for the observed variation in lithology immediately below the contact. The erosional, undulatory character of the the contact at Sawtooth Mountain and presence of a paleosol(?) on the top of the Lombard at Sheep Creek Canyon implies a disconformable relationship between the two units.

Tha absence of biostratigraphically useful fossils directly above and below the transition precludes any precise statement regarding the duration of the hiatus represented by the contact. The lack of laterally continuous outcrops along which the transition can be traced also inhibits recognition of angular relationship or gradational changes. Thus, the disconformity observed in outcrop may be better classified as a diastem. The inferred disconformable character of the contact at both Sawtooth Mountain and Sheep Creek Canyon indicates that the regional Lombard-Conover Ranch contact should be extended into the Snowcrest Range-Blacktail Mountains area.

LOMBARD LIMESTONE DEPOSITIONAL MODEL

Early late to late Meramecian

Following initial subsidence of the Snowcrest trough and nearshore deposition of the Kibbey Formation in middle Meramecian time, the southwestern end of the trough subsided rapidly. This abrupt change in the depositional environment is reflected in the initiation of carbonate deposition in the study area. Two major mechanisms may account for this pronounced change in basin sedimentation.

First, accelerated basin subsidence and the resulting marine flooding of the basin in early late Meramecian time caused the siliciclastic-dominated Kibbey shoreface to migrate northeastward within the trough. The absence of an interfingering relationship between the basal Lombard and upper Kibbey in the study area and elsewhere in southwestern Montana, and the abrupt appearance of carbonate deposits on Kibbey sandstones and siltstones indicate a rapid change in relative sea level with a lateral shift of the Kibbey depositional environment. A rapid eustatic rise in sea level is not envisioned as the cause of this flooding event because the record of rising sea level documented in the Amsden Group of the time-equivalent Wyoming basin indicates a constant and progressive rise in sea level from late Meramecian through Pennsylvanian time (Sando et al., 1975).

A carbonate bank complex (Scott Peak Formation) to the west on the outer cratonic platform continued to upbuild throughout this time (Stamm, 1984; P. E. Isaacson, personal communication, 1985), acting as a submerged sill at the mouth of the subsiding Snowcrest trough. This complex also was present during Kibbey deposition, confining terrestrial sedimentation to the trough (Sando, 1976; plate 4-A). That the carbonate bank was not drowned during late Meramecian time implies that a rapid eustatic sea level rise probably did not occur, or that upbuilding of the bank kept pace with the rising sea level. If a rise in relative sea level occurred it was brief and did not radically alter continued development of the bank complex (P. E. Isaacson, personal communication, 1985).

Second, clastic input into the depositional basin was substantially diminished, permitting the introduction and proliferation of carbonate-secreting organisms and carbonate detritus into the basin. This cessation of terrigenous influx may reflect a reduction of the sand and silt supply at source areas to the northeast and possibly the north. Alternatively, mild elevation of the Lombard arch at this time may have restricted connection of the basin with the clastic source area to the northeast. More significantly, the northeastward migration of the Kibbey shoreface resulted in entrapment of most terrigenous detritus by Kibbey tidal flat, estuarine, and foreshore areas near the head of the trough. A region of mixing of the Lombard carbonates and Kibbey foreshore clastics may have existed somewhere northeast of the study area.

It is apparent that subsidence in the southwestern end of the Snowcrest trough occurred simultaneously with tectonic elevation, stability, or slower subsidence of the outer platform-bank complex (plate 4-A). In concert with increased subsidence in the Snowcrest trough, uplift of the east-west-trending southern Montana arch began separating the Snowcrest trough and Wyoming basin (Sando, 1976; fig. 7). Thus, by late Meramecian time the Snowcrest trough had become a well defined basin.

Because the amount of positive topographic relief attained by the bank relative to the Snowcrest trough is uncertain, the degree of restriction over the bank is unknown. Some restriction is evident, however, as the lower part of the Lombard package is dominated by dark, spicular lime mudstones displaying evidence of deposition in quiet, dysaerobic water (lime mudstone lithofacies).

Analysis of the intertonguing relationship between the lime mudstone and fossiliferous wackestone-packstone lithofacies with respect to the position of the mouth and head of the Snowcrest trough suggests that the former lithofacies represents deep water deposition, below normal wave base, whereas the latter reflects shallow water deposition above normal wave base (see Plates 3 and 4-B). Three lithofacies belts are recognized which shifted laterally in the Snowcrest trough throughout Lombard deposition. These facies belts correspond well with those predicted by Shaw (1964) and Irwin (1965). They suggested that three facies belts should develop in an epeiric sea in which depositional strike approximately parallels the basin margins. The seaward belt reflects deposition below normal wave base; the intermediate belt documents deposition in shallow, agitated water where normal wave base and the basin floor intersect; and a landward belt is also developed in shallow water, but under less agitated conditions because most of the wave energy is damped across the intermediate facies belt.

The southwestern part of the basin was deep and vertically stratified, as represented by the thick accumulation of dark, organic-rich, spicular mudstones found in all Lombard sections exposed southwest of the Sliderock Mountain area (Plate 3). These rocks were deposited below wave base under dysaerobic conditions which precluded habitation by a shelly epifauna, but allowed soft-bodied infauna to thrive. The silling effect of the bank complex was apparently effective enough to reduce or inhibit mixing of the Lombard sea with the open ocean, promoting development of a vertically stratified Lombard sea. Periodic increase in the degree of restriction and/or elevation of the pycnocline (Byers, 1977) caused anoxic bottom water conditions, manifest in the laminated lime mudstone intervals. Episodic storm events transported bioclastic material and phosphatic pellets from the shallow bank environment and/or metazoan-rich, shallow water facies belt into the deeper parts of the basin, resulting in deposition of thin, macrofossil-rich beds. The detrital phosphatic pellets suggest that upwelling processes were operating along the bank, ultimately promoting phosphorite formation.

Shallow water deposition occurred in the northeastern part of the basin, where intersection of the basin floor and normal wave base resulted in slightly to moderately turbulent, well oxygenated water (plate 3). A diverse shelly fauna, dominated by stalked echinoderms, bryozoans, and brachiopods was established in this part of the basin. As these faunal constituents died and were disarticulated, moderately energetic waves and currents redistributed the bioclasts into broad, sheet-like deposits. Proliferation of the carbonate-secreting organisms and the production of additional carbonate detritus caused upbuilding toward sea level and deposition of more mature limestones, such as biosparites and biopelsparites. Upon nearing sea level deposition of the fossiliferous limestones spread laterally, prograding southwestward over the deeper water lime mudstone deposits (Plate 3).

Farther northeast and along the trough margins, the siliciclastic Kibbey tidal flat and shoreface deposits continued to develop and migrate up the trough as sea level rose and/or basin subsidence continued (plate 4-B). Wave energy in this environment was probably very low as a result of damping of the waves and tidal currents across the shallow water, fossiliferous wackestone-packstone belt.

The threefold facies pattern which existed in the basin during the early period of Lombard deposition indicates that subsidence was greatest to the southwest and progressively less to the northeast. Thus, a gentle ramp was established, which was truncated somewhere west of the study area against the eastern side of the Scott Peak bank complex (plate 4-B).

Following initial differential subsidence which produced a down-to-the-southwest basin profile, subsidence rates appear to have remained uniform throughout the trough. A thick lime mudstone lithofacies sequence was consequently deposited in the southwestern half of the study area, while thin fossiliferous wackestone-packstone tongues developed and episodically prograded westward in the northeastern part (Plate 3).

Although subsidence was probably uniform throughout the trough, one major overprinting relationship can be recognized and a second inferred in the Lombard stratigraphic record. First, the thin fossiliferous wackestone-packstone tongues, separated by northeastward-pinching lime mudstone tongues, indicate that in the northeastern part of the trough (a) basin subsidence was episodic, (b) rising sea level periodically outpaced carbonate buildup and progradation, or (c) a combination of the two occurred. Thus, the shallow-water tongues reflect cyclic re-establishment and lateral progradation of the shelly fauna deposits, followed by drowning and retrogradation.

Most of the lateral and vertical transitions from the deep to shallow water lithofacies are gradational, connoting gradual, though episodic, subsidence. However, sharp basal contacts and lithological transitions between some deep water and superjacent shallow water deposits, such as occur at the base of tongue IIIS at Snowcrest Mountain, imply abrupt cessation of subsidence and possible slight uplift of isolated areas at the northeastern part of the trough.

Second, basin subsidence and/or rising sea level may have migrated northeastward, enlarging the depositional basin. This is suggested on Plate 3 by the progressive northeastward advance of the lime mudstone tongues during deposition of the lower part of the Lombard. In the absence of data on the Lombard between the Greenhorn Range and Horseshoe Hills area (fig. 1; plate 3) this ideal northeastward migration of the episodic deep water facies cannot be firmly established. The lower half of the Lombard in the Tendoy Range area, however, is late Meramecian in age (Sando et al., 1985), while the Lombard in the Bridger Range is entirely Chesterian (Guthrie, 1984). Progressive northeastward expansion of the depositional basin is also suggested by isopach data of complete Lombard sections which are significantly thinner toward the head of the trough (figs. 52 and 53). A diachronous relationship within and between the Kibbey and Lombard is thus established (fig. 49). Episodic migration of the deep water facies to the northeast, therefore, seems probable in light of the hypothesis that a gradual, progressive eustatic rise in sea level occurred during Kibbey and Lombard time.

It is interesting to note that the shallow-water facies tongues appear to have migrated progressively southwestward upsection in the lower part of the Lombard, establishing a mirror-image type of symmetry relative to the deep water facies tongues (plate 3). Progressive elevation of sea level may have accentuated tectonic fluctuations in the trough creating a pendulum-like relationship between the tongues. This apparent mirror-image relationship may not exist, however, as the lateral extent of the individual tongues is poorly defined on outcrop.

The lower part of the Lombard, dominated by the lime mudstone lithofacies, is inferred to be late Meramecian in age. This age is suggested by the intimate lithostratigraphic relationship between the carbonate bank complex (Scott Peak Formation) and the deep, quiet water lime mudstones deposited behind the restricting bank (plate 4-B). Upbuilding of the carbonate occurred from middle Meramecian (Foraminifera Zone 13) to latest Meramecian-earliest Chesterian time (Foraminifera Zone 15-16i; Stamm, 1984). A late Meramecian age for the lower part of the Lombard, therefore, is indicated by both biostratigraphic and

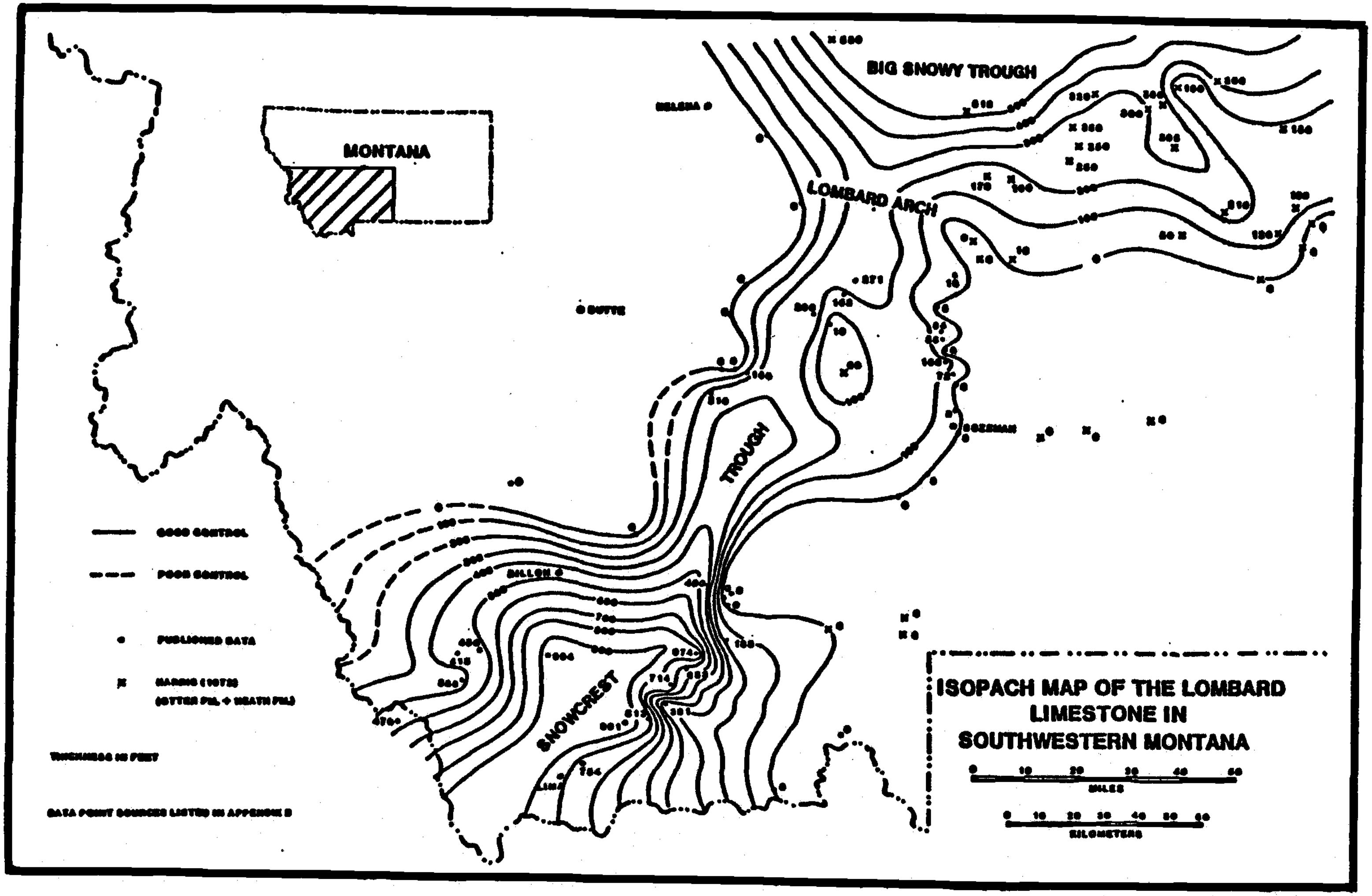


Figure 52. Isopach map of the Lombard Limestone in southwestern Montana. Contour interval is 100 feet. Figure by the author.

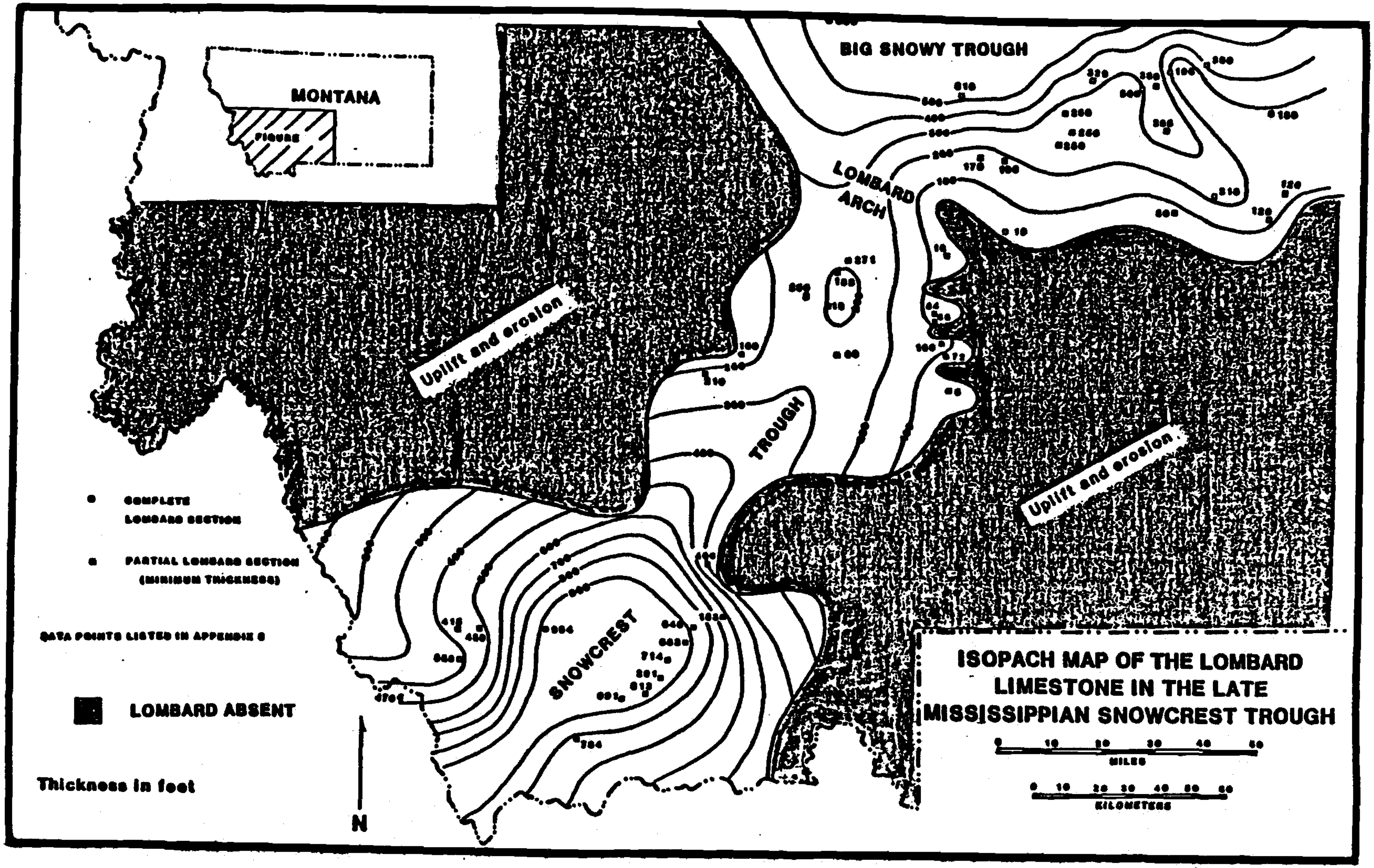


Figure 53. Isopach map of the Lombard Limestone in the Late Mississippian Snowcrest trough. Darkened regions represent areas of syn- or post-Lombard uplift and erosion. Contour interval is 100 feet. Figure by the author.

lithostratigraphic evidence.

Early to middle late Chesterian

In earliest Chesterian time (Foraminifera Zone 16i) a pronounced change in the depositional environment took place on the edge of the outer platform. The Scott Peak bank complex, which persisted throughout middle and late Meramecian time, ceased developing in response to an abrupt deepening event (Skipp et al., 1979; Stamm, 1984). Carbonate bank deposition as far east as the Beaverhead Mountains area,during the Meramecian, was replaced by deposition of barren, limy siltstones and claystones of the Railroad Canyon Formation, and silty, argillaceous lime mudstones of the South Creek Formation (plate 4-C; Wardlaw and Pecora, 1985; Skipp et al;, 1979). The laminations and fissile splitting habit on outcrop suggest deposition in deep water, below normal wave base, and probably below or in the lower reaches of the photic zone. Increased subsidence, or a rise in sea level which exceeded bank sedimentation, or a combination of these processes may explain this drowning event.

Deepening of the sea across the bank probably initiated improved circulation in the Snowcrest trough, enhancing mixing of the basin water with the open ocean. The vertically stratified, dysaerobic basin water was consequently replaced with aerobic water, permitting a rapid proliferation of the shelly fauna. The upper part of the Lombard consists predominantly of fossiliferous wackestones and packstones, and subordinate grainstones, diagnostic of shallow-water sedimentation (tongues IVS-VIS). Shoaling in the present day Blacktail Mountains and Lombard Station area (at the northeastern end of the trough) was extreme enough to promote the development of stagnant lagoons, which are represented by thin coal seams (Harris, 1972; Pecora, 1981).

The Lombard sea probably extended at least to the present-day Bridger Range area (plate 4-C). Complete breaching of the Lombard arch and major ingression of marine water into the Big Snowy trough may also have occurred, initiating Kibbey and Otter deposition there (fig. 49). Nearly synchronous deposition of shallow water, moderately mature and mature, macrofossil-rich limestones across most of the basin signaled abrupt changes in water depth, depth of normal wave base, aerobicity, bottom slope, and/or basinwide subsidence.

This event may be documented in the transition from lime mudstone tongue IVD to fossiliferous wackestone-packstone tongue IVS as corals, Siphonophyllia sp. and S. excentrica Meek, diagnostic of a Chesterian age were found within and above these tongues, but not in those below. Deposition of calcareous, unfossiliferous siltstones, claystones, and shales was also initiated in the present day Beaverhead Mountains area at this time (Wardlaw and Pecora, 1985).

It seems that the relative subsidence of the outer cratonic platform with respect to the inner platform switched in magnitude. That is, the slow subsidence and/or uplift of the outer platform area which prevailed earlier was replaced by greater rates of subsidence or a cessation of uplift. Conversely, subsidence in the Snowcrest trough decreased and/or slight tectonic uplift was initiated (plate 4-C and 4-D). In light of the thick fossiliferous wackestone-packstone package which characterizes the upper part of the Lombard in the study area, however, basin subsidence and/or elevation of sea level must have continued (see plate 3). Proliferation of the carbonate secreting organisms in the shallow, agitated, silt-free basin may have induced a high sedimentation rate which maintained equilibrium with, or exceeded, basin subsidence, generating the thick shallow water limestone sequence. The thinner South Creek and Railroad Canyon Formations, which reflect the deepening event on the outer cratonic platform, may have resulted from: (1) tectonic subsidence exceeding upbuilding, and/or (2) inhibition of the carbonate-secreting epifauna by increased water depth, dysaerobic bottom water conditions, and/or silt-laden water. Deeper water sedimentation on the outer platform (South Creek and Railroad Canyon Formations) thus passed northeastward into a shallow marine depositional environment (upper part of the Lombard) during early Chesterian time (plate 4-D).

This deep-to-the-west, shallow-to-the-east relationship appears to have prevailed throughout most of upper Lombard and Railroad Canyon deposition; the lower 439 feet of the 676 foot thick Railroad Canyon section consists of limy claystones, siltstones, mudstones, and shales (Wardlaw and Pecora, 1985). Rare grainstones, wackestones (sparse biomicrites), and mud chip-bioclast limestone conglomerates in the middle third of the Railroad Canyon (Wardlaw and Pecora, 1985), however, suggest that sedimentation near the mouth of the Snowcrest trough occurred close enough to normal wave base to be influenced by slight deepenings of the wave base, drops in sea level, or depositional upbuilding to this zone of agitation. Conversely, some of the rare deposits may reflect catastrophic sedimentation associated with major storm events and/or turbidity currents generated in the east, south, or north.

At the extreme southwestern end of the thesis area the thick, fossiliferous upper Lombard sequence splits into three thick tongues (IVS, VS, VIS). These are separated by two thick deep-water lime mudstone tongues (VD, VID), which successively display a southwestward aspect higher in the section (plate 3). This part of the trough, therefore, acted as a transition zone between shallow and deep water deposition, possibly in response to differential subsidence across this zone or a slight increase in bottom slope to the west.

The two major lime mudstone tongues generally are identical to the lime mudstone tongues in the lower part of the Lombard. The absence of a carbonate bank to the west at this time (early Chesterian to middle late Chesterian) precludes employment of a vertically stratified, silled basin model to explain the lack of a shelly fauna and abundant infauna. Perhaps these quiet water deposits reflect sedimentation on a gently seaward-dipping, distally steepened ramp, well below the normal wave base where the top of the oxygen minimum zone impinged upon the platform. Silt is a moderately common constituent in the carbonates of the Railroad Canyon Formation to the west, but seldom exceeds six percent in the lime mudstone beds in the study area. Thus, silting of the water cannot be called upon to explain the decreased carbonate production. A second possibility is that the drowned bank complex maintained slight positive relief adjacent to a slightly negative topographic depression in the basin floor at the southwesternmost end of the trough. Such a relationship may have produced local anaerobic bottom conditions in the small, gently silled basin. A similar model has been employed to explain the occurrence and distribution of the laminated limestone facies of the middle Silurian Roberts Mountain Formation (Matti and McKee, 1977). Vertical "bobbing" of this local instability might also explain the twice-repeated transition from deep dysaerobic to shallow aerobic sedimentation.

The uppermost shallow water tongue thins slightly to the southwest, and progrades out of the thesis area. Several specimens of Siphonophyllia sp. are present in this tongue at the southwesternmost section in the study area, indicating early to late Chesterian deposition (Foraminifera Zone 16i to middle 18). The presence of similar corals, Siphonophyllia sp. and S. excentrica Meek, at the base of the fossiliferous upper Lombard section, approximately 360 feet lower in the section, suggests that this tongue should be assigned a late Chesterian age.

The uppermost part of the Railroad Canyon Formation is a 55-foot thick cross-laminated siltstone and limestone interval which is temporally correlative to the Conover Ranch Formation (Wardlaw and Pecora, 1985). Directly underlying this uppermost interval are 181 feet of fossiliferous limestone bearing a shelly fauna similar to that in the upper part of the Lombard. This macrofossil-rich sequence stands in sharp contrast to the underlying claystones, siltstones, and shales which characterize most of the Railroad

Canyon section, and indicates a significant change in depositional environment. Conodonts and brachiopods diagnostic of early to late Chesterian deposition occur in the fossiliferous Railroad Canyon limestones. On the basis of biostratigraphic and lithostratigraphic relationships the thick, macrofossil-rich interval near the top of the Railroad Canyon can be correlated tentatively to the uppermost shallow water tongue of the Lombard.

Middle late Chesterian

In middle late Chesterian time (Foraminifera Zone 17, upper part) shoaling was initiated on the outer cratonic platform, probably as a result of tectonic uplift or cessation of subsidence. This change is marked by the return of carbonate bank deposition and upbuilding in the same area as the previous Scott Peak bank complex (plate 4-E). The contact between the deep water South Creek deposits and overlying Surrett Canyon bank deposits is covered, but the transition is recognized as a progressive increase in mud mound and Waulsortian mud mound deposition (P. E. Isaacson, personal communication, 1985).

Initial deposition of the Surrett Canyon bank limestones coincides in time with the final stages of Lombard deposition (Fig 49). Westward shoaling, possibly related to rates of subsidence progressively decreasing from east to west, is implied by progradation of the uppermost fossiliferous wackestone-packstone tongue in the Lombard from the Snowcrest trough through the Railroad Canyon area. Shoaling in the present day Snowcrest Range area climaxed at this time as a sequence of thick, fossiliferous packstones which pass upward into fossiliferous and slightly oolitic grainstones, which at a few places are overlain by lenticular limestone lithoclast conglomerates. These deposits reflect deposition in a shallow, turbulent, subtidal platform environment with local carbonate bar and subtidal channel development. Regionally, this shoaling event may coincide with the shoaling event occurring on the outer platform at the beginning of Surrett Canyon deposition.

As buildup of the Surrett Canyon bank progressed, and/or uplift occurred on the outer cratonic platform, silling at the mouth of the Snowcrest trough was reinitiated. Consequently, a vertically stratified water column was established in the basin, creating anoxic benthos conditions inimical to epifaunal and infaunal taxa. In addition to pronounced changes occurring on the outer platform and within the Snowcrest trough, tectonic instability external to the depositional basin resulted in an accelerated influx of terrigenous clastic material. This acute alteration of the depositional environment is recorded in the thick, calcareous shale sequence overlying the thicker fossiliferous wackestone-packstone sequence (tongues IVS-VIS) of the upper part of the Lombard (plate 3).

While outer platform subsidence had substantially slowed or ceased, and/or started rising slowly, and tectonic instability in the region north or northeast of the basin was renewed, the tectonic character within the Snowcrest trough at this time is uncertain. The faunal similarity of the upper Lombard shales to the spicular lime mudstones in the lower Lombard implies the return of an environment somewhere in the basin conducive to the occurrence of sponges in excess of other faunal elements. Textural dissimilarities, such as the widespread absence of bioturbation, presence of pyrite, and local presence of abundant phosphatic pellets, implies sedimentation in a unique Lombard depositional environment. Two models can be hypothesized to explain the origin of the calcareous shales.

In the first model, subsidence in the Snowcrest trough remained slow or stopped, and a shallow, stagnant sea developed behind the submerged carbonate sill to the west. The fetch in the basin may have been significantly reduced by falling sea level or tectonic elevation of the basin, limiting the depth of normal wave base associated with wind-driven waves. If the sea was essentially stagnant and anoxic throughout, carbonate production would tend to be inhibited or significantly decreased (Enos, 1983).

The time span represented by the calcareous shales and overlying dolomitic lime mudstones is unknown, but is believed to have been relatively short because late and latest Chesterian brachiopods (Foraminifera Zones middle 18 to 19) occur in the overlying Conover Ranch Formation, and early to late Chesterian corals occur near the top of the underlying, youngest shallow water Lombard tongue (tongue VIS; C. F. Key and W. J. Sando, personal communication, 1985). Accumulation of a 148 foot thick shale sequence over a short time period would necessitate a moderate to rapid sedimentation rate which seems unlikely in a stagnant sea.

The bioclast assemblage, dominated by sponge spicules, was possibly transported in suspension into the shallow sea from the carbonate bank or some other, unrecognized source by weak (damped) tidal currents or wind-generated waves. Transportation of the dense, detrital(?) phosphatic pellets is more difficult to rationalize, however, if currents and waves in the restricted sea were so weak and attenuated that the water had become nearly stagnant.

The second, favored, model involves subsidence of the Snowcrest trough behind the carbonate bank and consequent deposition in a deep, vertically stratified basin. Subsidence in excess of sedimentation in the axial part of the Snowcrest trough would cause development of anoxic bottom water conditions in the deepest parts of the basin, below the pycnocline, and rapid migration of the fossiliferous wackestone-packestone lithotope toward the bank and the trough margins (plate 4-E). Depth and associated anaerobicity are envisioned as the primary factors responsible for the lack of benthic infauna and epifauna in the calcareous shales. Greater subsidence than during any previous period of Lombard deposition additionally explains the development of this unique Lombard lithofacies.

The uppermost Lombard at the head of the trough, in the Bridger Range area, is characterized by fossiliferous wackestones and packstones interbedded with lime mudstones. The wackestone and packstone beds consist predominantly of pelagic foraminifers, sponge spicules or brachiopod spines, and scarce solitary corals. Late Chesterian conodonts also occur in these beds (Guthrie, 1984). Thus, they may be approximately correlative in time with the fossiliferous wackestone-packstone to calcareous shale transition in the upper Lombard in the study area.

The disconformity between the Lombard and the Conover Ranch in the Bridger Range area, however, does not permit a reliable correlation with either the shale or the overlying dolomitic lime mudstone lithofacies because the amount of missing section is unknown. The calcareous shale and dolomitic lime mudstone lithofacies also are missing in the Blacktail Mountains, just north of the study area, and farther west at Railroad Canyon (Beaverhead Mountains; fig. 1). Fossiliferous wackestones and packstones with interbedded lime mudstones and silty lime mudstones dominate the upper part of the Lombard at both locations (Pecora, 1981; Wardlaw and Pecora, 1985). The Lombard-Conover Ranch contact at Sheep Creek Canyon may be unconformable, as previously established. Several specimens of *Duncanopora* sp., occur here in a fossiliferous wackestone bed 37 feet below the base of the Conover Ranch. This coral is diagnostic of Coral Zone VB, indicating late Chesterian deposition (Foraminifera Zone 17 to middle 18; W. J. Sando, written communication, 1985). Thus, the beds above this may correlate in time with the calcareous shales. The amount of Lombard section missing at the Lombard-Conover Ranch contact at Clover Meadow, in the north-central Gravelly Range, is unknown. As at Sheep Creek Canyon, the uppermost Lombard is made up of fossiliferous wackestones and packstones of Chesterian age. While correlation to the uppermost Lombard beds in the Bridger and Gravelly Ranges may not be tenable, correlation of the calcareous shale sequence with the uppermost Lombard rocks at Sheep Creek Canyon, Railroad Canyon, and the Bridger Range area has merit.

If the contacts at Sheep Creek Canyon and Clover Meadow are conformable the shales may have been deposited within a narrow, deep, anoxic part of the basin, approximately centered in the study area. Conversely, the shales may have been widespread within the trough, but subsequently removed by post-Lombard, pre-Conover Ranch uplift and erosion. Post-Lombard, pre-Conover Ranch uplift and erosion, or unrecognized thrust faulting is inferred at the southwestern end of the study area (Red Rock River section); the absence of shales here, therefore, is not interpreted to be the result of non-deposition.

The deep water model may also facilitate moderate sedimentation rates, in contrast to the shallow, stagnant sea model. In a deep, vertically stratified basin the uppermost part of the water column could be well oxygenated and support an abundant planktonic, carbonate-secreting fauna. Carbonate detritus would also be carried into the axial parts of the trough from the peripheral shallow water areas and/or the carbonate bank complex by regular tidal currents. The fine bioclast assemblage in the shales implies attenuated waves and currents incapable of transporting larger bioclastic debris, although these coarser grains may have been deposited from suspension or bedload somewhere between the shallow and deep water area. If the greater depth of the sea can be related to greater areal trough dimensions, then wind-generated waves resulting from a larger fetch may have been able to transport coarser debris greater distances; this may explain the origin of detrital phophatic pellets in the shales.

The detrital phosphatic pellets suggest periodic phosphorite precipitation on the northern(?) end of the bank complex associated with south-southeastward-directed upwelling in the miogeosyncline (upwelling induced by west-southwest blowing paleotrade winds). The pellets in the shales may reflect seasonal storms which caused disaggregation of the phosphatic nodules or pellets on the bank and subsequent transport into the deep parts of the Snowcrest trough.

In the final stages of Lombard deposition, basin subsidence slowed, sea level fell, and/or circulation in the platform sea improved slightly, causing deepening and/or destabilization of the pycnocline (plate 4-E). Dysaerobic bottom conditions progressively replaced anoxic bottom conditions as documented in the gradational transition from the azoic, laminated calcareous shale to the bioturbated dolomitic lime mudstone lithofacies (plate 3). The abundant infauna connoted by widespread bioturbation, and the absence of any carbonate-secreting benthic fauna suggest dysaerobic conditions prevailed in the basin throughout the remainder of Lombard deposition. The paucity of bioclasts, nowhere exceeding ten percent of the total constituents, suggests the development of a stressful environment which inhibited habitation of carbonate-secreting organisms. On the other hand, dissolution or destruction of most bioclastic material by chemical and/or biological processes may have resulted from slow sedimentation rates and prolonged exposure at the sediment-water interface.

Coincident with the initiation of lime mudstone deposition, the influx of clastic material into the trough decreased, implying that uplift in the extrabasinal area had slowed or ceased, or that the sediment was diverted elsewhere. Dolomitization of the lime mudstones followed bioturbation, as discussed in an earlier section. Uplift in the northeastern part of the trough or substantial shoaling may have facilitated the development of a meteoric mixing system which induced dolomitization of these rocks. Rapid regression of the sea at the end of Heath deposition in the Big Snowy trough (Maughan, 1984) may correspond in time with this dolomitization event (plate 4-F).

Evidence of supratidal or intertidal deposition is not present in these rocks. Deposition of the rocks of this lithofacies, therefore, is inferred to have occurred in a dysaerobic carbonate sea of shallow to intermediate water depth. A shallow, fossiliferous limestone belt probably continued to develop along the basin margins. The areal extent of deposition of the dolomitic lime mudstone lithofacies is unknown. The dolomitic lime mudstone lithofacies has neither been recognized nor reported elsewhere in southwestern Montana. Complete withdrawl of the Lombard sea prior to Conover Ranch deposition is implied by the unconformity between these two units which is pervasive in most of the study area. Thus, the original area of dysaerobic lime mudstone sedimentation may be falsely represented by the present-day restricted distribution of this lithofacies. On the other hand, these rocks may have been deposited in a narrow, slightly deeper part of the trough, flanked by fossiliferous limestones laid down in shallower water above wave base.

Latest late Chesterian

Transgression of the sea continued into Pennsylvanian time in the Wyoming basin (Sando, 1976). The close of Lombard and Heath deposition in the Snowcrest and Big Snowy troughs, respectively, is constrained to a late to latest Chesterian age, however, by biostratigraphic data. Regression of the sea must, therefore, be the result of nearly simultaneous uplift in the Big Snowy and Snowcrest troughs (fig. 49).

The Lombard and Conover Ranch are conformable in the Tendoy Mountains (Sando et al., 1985; Wardlaw and Pecora, 1985). Thus, the sea must have withdrawn to some position midway between the study area and the present day Tendoy Mountains area near the close of late Chesterian time (Foraminifera Zone 18, middle to upper part; fig. 49)(plate 4-G). Deposition of cross-laminated sandy siltstones and thin- to medium-bedded limestones, which characterize the uppermost Railroad Canyon Formation (Wardlaw and Pecora, 1985), probably began or was continuing at this time. Renewed subsidence in the basin, continued rise in regional sea level, and/or brief subsidence of the Surrett Canyon bank complex subsequently occurred, initiating deposition and onlap of the transgressive Conover Ranch on the eroded Lombard deposits (C. F. Key, in preparation, 1985).

PETROLEUM POTENTIAL

Prior to the late 1960's, few workers focused on the petroleum potential of the Lombard Limestone (Big Snowy Formation). In one of the earliest investigations dealing with both the Paleozoic and Mesozoic rocks in southwesternmost Montana, Scholten (1967) alluded to the poor oil potential of the region because of the long, complicated tectonic history. Mid- to Late-Cretaceous uplift and subsequent exposure of pre-Cretaceous source rocks along the flanks of the major anticlinoria (fig. 8) were the main reasons for this pessimistic outlook. Scholten (1967) concluded "...it may be expected that most, or all, hydrocarbons migrated to the surface at that time and were transported by surface waters or dissipated into the air."

Thirty-one wildcat wells have been drilled in southwestern Montana as of 1983 (Perry et al., 1983). To date, none have produced commercial quantities of oil or gas, and most have reported only minor shows of either. Two stratigraphic holes were drilled at the northern end of the study area in 1984 (fig. 54); results of these wells presently are not available (Pat McGraw, personal communication, 1985; these wells are W. G. Ellis Estate #1 and #2, T. 8 S., R. 5 W.). These are the only two wells which test the Snowcrest trend. Well locations near the study area are illustrated on Figure 54.

Detailed geochemical analyses of the Lombard (Big Snowy Formation) in southwestern Montana have concentrated on sample collections from surface exposures on the Tendoy thrust sheet

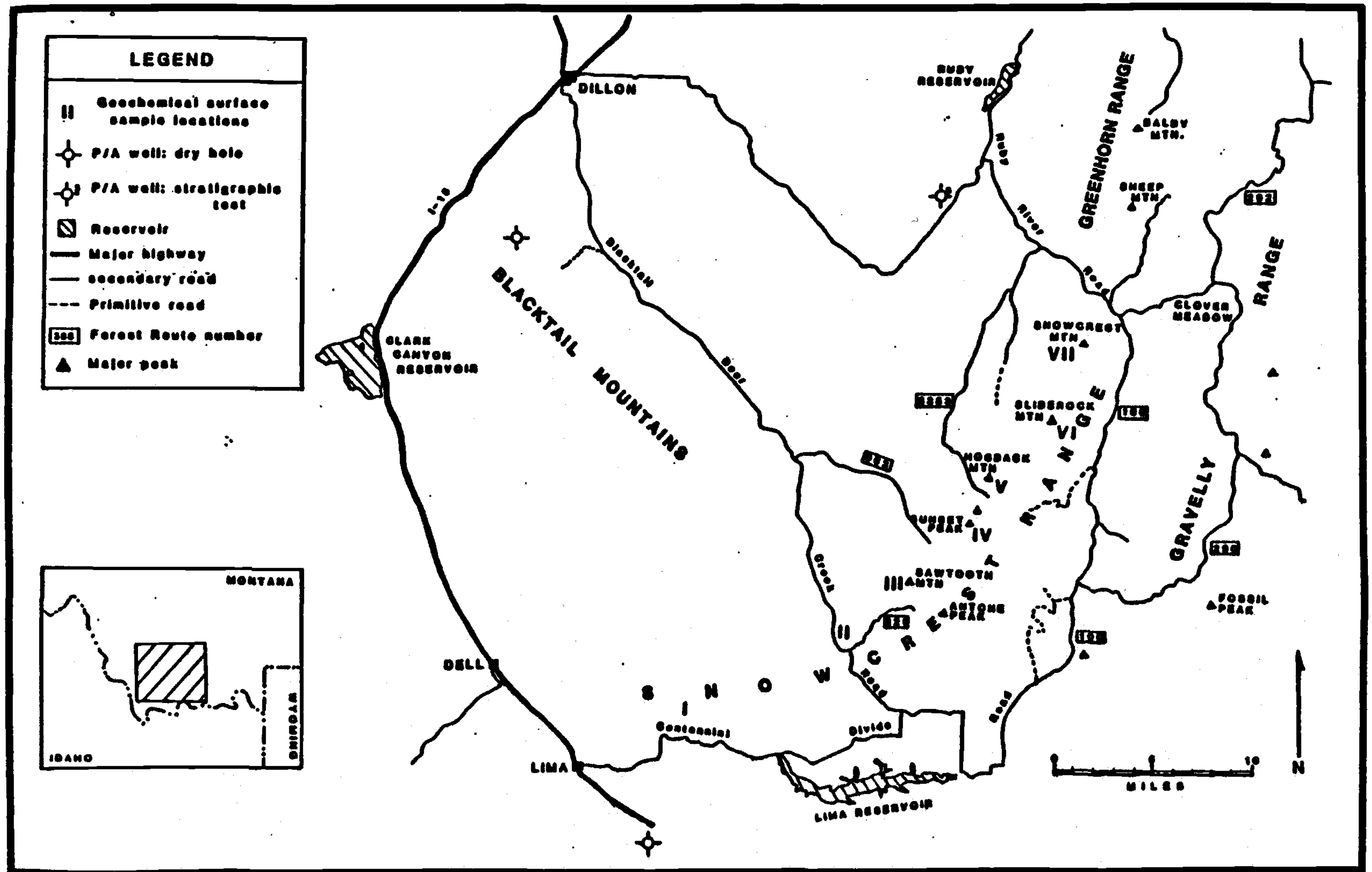


Figure 54. Map of southwesternmost Montana showing abandoned well locations and surface sample collection locations for source rock analyses.

(Swetland et al., 1978; Perry et al., 1981, 1983). Geochemical data east of the overthrust belt are sparse. In a petroleum source beds study of the northern Rocky Mountain region, Swetland and others (1978) collected five surface samples from the lower part of the Lombard (lime mudstone lithofacies) at Clover Divide (Blacktail Deer Creek Road; their locality 8), which yielded a total organic carbon value of 1.8 percent. No other geochemical analyses were completed.

Recent work in the Snowcrest-Greenhorn-Blacktail area has provided new impetus for reconsideration of the petroleum potential of the Lombard Limestone in southwesternmost Montana. Analyses of major stratigraphic and structural trends suggest the likely presence of a deep-seated, northeast-trending sub-Snowcrest Range thrust fault which soles or underlies the subordinate Snowcrest and Greenhorn thrust faults (Perry et al., 1981, 1983; Kulik, 1984). Five points of evidence are presented by Perry and others (1983) which substantiate the existence of this major Laramide thrust fault. Gravity, aeromagnetic, structural, and stratigraphic data further suggest that the inferred sub-Snowcrest Range fault extends westward beneath the Tendoy and Medicine Lodge thrust sheets (fig. 55). The significance of a major sub-Snowcrest Range detachment fault lies not only in the possibility that potential petroleum source rocks are buried beneath the leading edge of the southwestern Montana overthrust belt, but also that these same units may presently exist at depth in the autochthonous (footwall) block east of the overthrust belt (fig. 56). If the drag structure suggested in Figure 56 exists, and if the basement rocks and

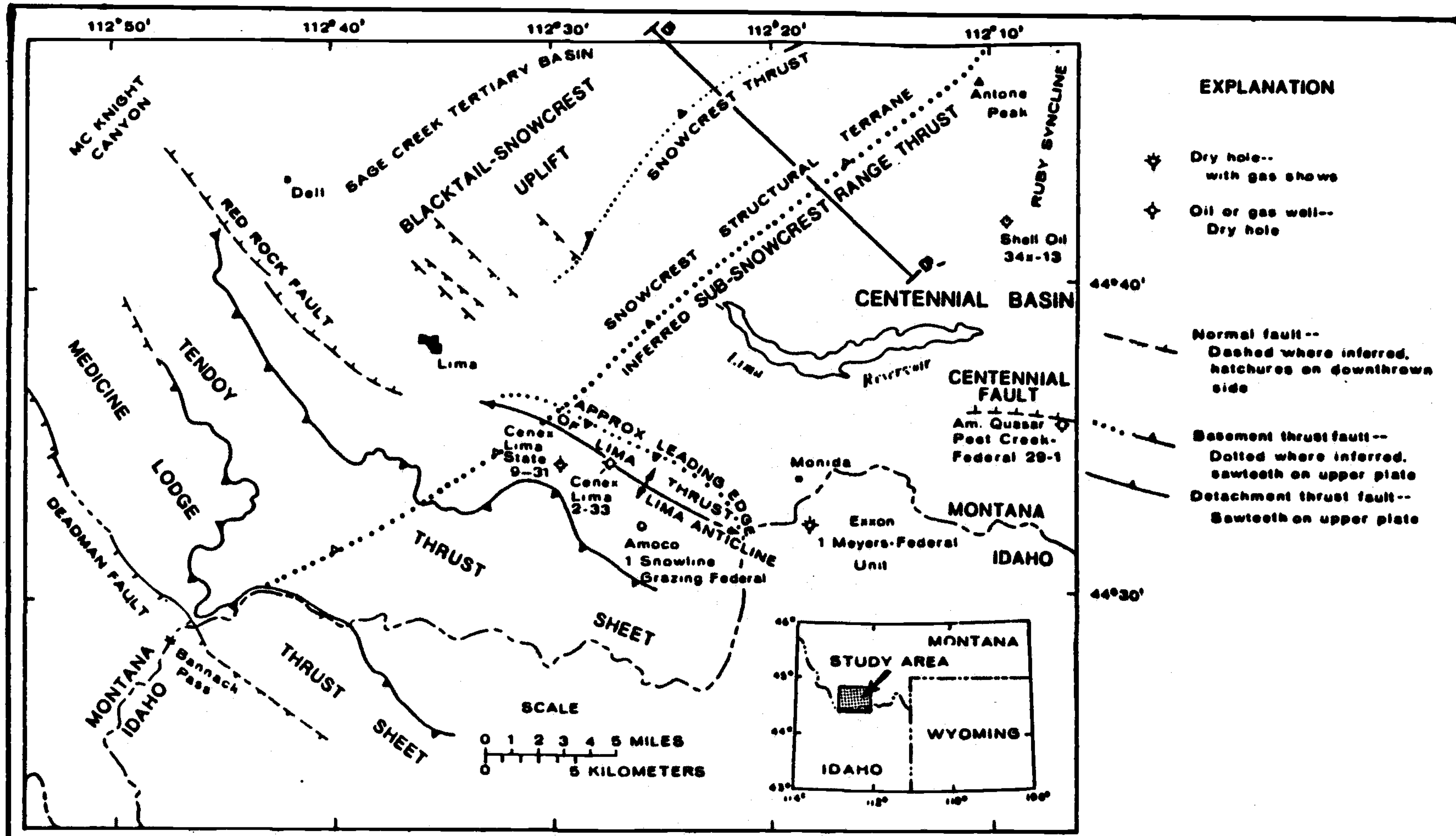


Figure 55. Generalized tectonic map of southwesternmost Montana showing position of inferred sub-Snowcrest Range thrust fault and relationship with Tendoy and Medicine Lodge thrust sheets (from Perry et al., 1983). Line B-B' corresponds to Figure 56.

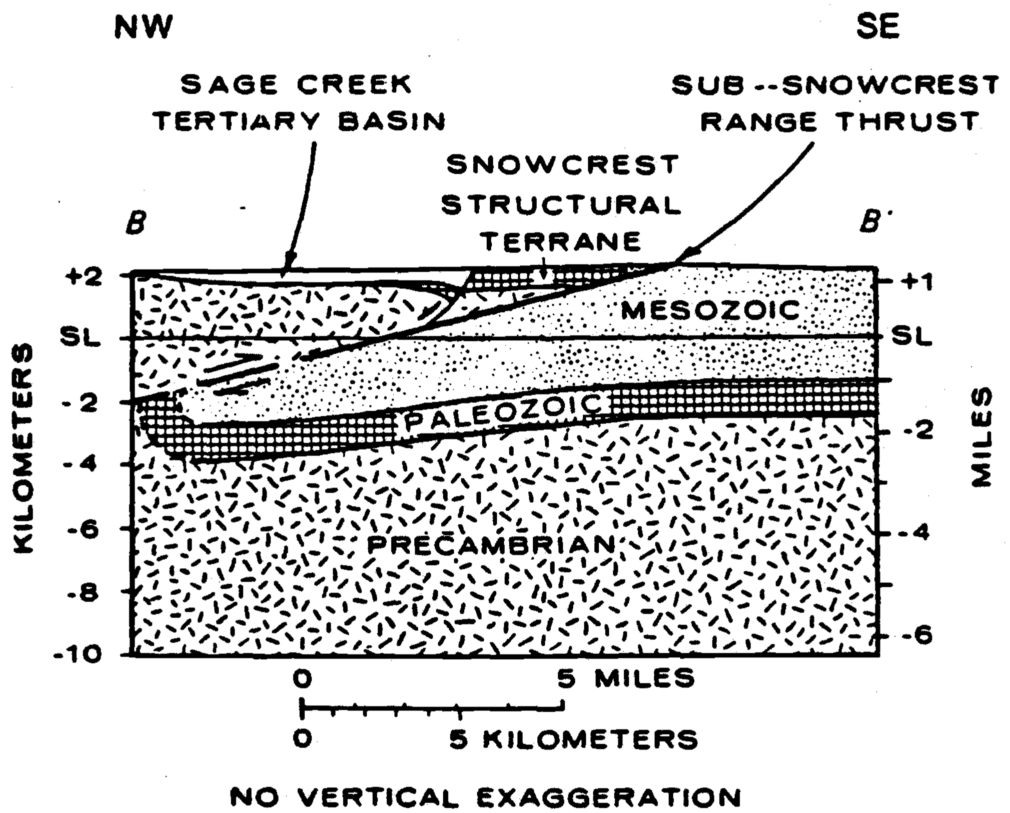


Figure 56. Hypothetical cross section B-B' through Snowcrest terrane (from Perry et al., 1983). Line of section shown on Figure 55.

bracketing Mission Canyon and Conover Ranch units provide adequate seals, and if the thermal conditions are right, then an attractive oil play may be present.

Surface samples were collected by the author at seven locations in the Snowcrest Range (fig. 54; Appendix C). Most of the samples were obtained from the lime mudstone lithofacies of the lower part of the Lombard. Four samples were collected in the calcareous shale lithofacies and one sample was taken in the uppermost exposed fossiliferous wackestone-packstone lithofacies bed at Sunset Peak; this sample is included with the lime mudstone lithofacies in the following discussion. The samples were analyzed for thermal maturation, total organic carbon, extractable hydrocarbons (bitumens), and kerogen content and type(s) (table 3). Rock-eval pyrolysis and gas chromotography analyses were additionally completed on promising samples (see table 4 and Appendix D). All maturity ratings in the subsequent discussion are based on the carbonate standards used by Tenneco Oil Company (used with permission); these standards are listed on Figure 57.

Results and interpretation

Vitrinite reflectance values of 0.47Ro to 0.87Ro obtained from rocks of the lime mudstone and calcareous shale lithofacies suggest that the organic material is transitional or mature with respect to oil generation. Cross-referencing these thermal maturity indices with spore/pollen color values (3 to 3+), however, indicate that all of the Lombard rocks analyzed are thermally mature (see Table 3). The low vitrinite values in several of the samples are the result of

SOURCE ROCK EVALUATION DATA LOMBARD LIMESTONE														
Sample & Lith.	Spore Color	Vit. Ro	TOC %	HC ppm	INR %	Humic %	Humic ppm	Land Ex. %	Land Ex. ppm	Mar. Ex. %	Mar. Ex. ppm	Sapropelic %	Sapropelic ppm	Remarks
1 LM	3	0.82	0.31	0	50	18	558	0	0	0	0	32	992	Fresh contamination
2 LM	3	0.68	0.36	0	10	4	144	0	0	0	0	86	3096	Fresh contamination
3 LM	3	0.75	0.31	0	--	-	--	-	-	-	-			Too sparse
4 LM	3	0.79	0.19	0	--	-	--	-	-	-	-			Too sparse
5 LM	3	0.76	0.84	0	6	4	336	2	168	0	0	88	7392	Fresh contamination
6 LM	3	0.67	1.06	980	6	2	212	0	0	0	0	92	9752	Fresh contamination
7 LM	3	0.67	1.10	760	4	6	660	2	220	0	0	88	9688	
8 LM	3	--	0.31	0	18	0	0	2	62	0	0	80	2480	
9 LM	3	--	0.46	0	10	0	0	8	368	0	0	82	3772	Fresh contamination
10 LM	3	0.58	0.91	980	6	2	182	4	364	0	0	88	8008	Fresh contamination
11 CS	3	0.74	1.59	1690	12	2	318	4	636	0	0	82	13038	
12 LM	3+	0.87	0.71	2050	10	2	142	2	142	0	0	86	6106	
13 LM	3	0.83	0.23	660	--	-	--	-	--	-	-			Almost barren
14 LM	3	0.67	0.66	1270	18	6	396	4	264	0	0	72	4752	Fresh contamination
15 CS	3	0.47	1.39	3160	3	4	556	4	556	0	0	84	11676	Fresh contamination
16 CS	3	0.50	1.39	2300	22	2	278	2	278	0	0	74	10286	Fresh contamination
17 LM	3	0.82	0.23	0	18	2	46	0	0	0	0	80	1840	
18 LM	3	0.84	0.39	0	--	-	--	-	-	-	-			Too sparse
19 LM	3	0.82	0.16	0	--	-	--	-	-	-	-			Too sparse
20 LM	3	0.51	0.15	0	--	-	--	-	-	-	-			Too sparse; Contam.
21 LM	3	0.75	0.21	0	--	-	--	-	-	-	-			Too sparse
22 LM	3	0.73	0.22	0	--	-	--	-	-	-	-			Too sparse

Sample & Lith.: Sample number (see Appendix C)
Lithofacies: LM = Lime mudstone
CS = Calcareous shale
Vit. Ro: Vitrinite reflectance
TOC %: Total organic carbon (weight percent of rock)
HC ppm: Extractable hydrocarbons

INR %: Inertinite content
Humic: Humic kerogen content
Land Ex: Land exinite content
Mar. Ex: Marine exinite content
Sapropelic: Sapropelic kerogen content

Table 3. Data obtained from source rock evaluation of Lombard Limestone samples. Samples analyzed at Tenneco Oil Laboratories.

RESULTS OF ROCK-EVAL PYROLYSIS									
Sample & Lith	Tmax (C)	S1 (mg/g)	S2 (mg/g)	S3 (mg/g)	PI	PC*	TOC (%)	Hydro Index	Oxy Index
6 LM	433	0.15	3.02	0.40	0.05	0.26	1.06	284	37
7 LM	430	0.26	3.67	0.50	0.07	0.32	1.10	333	45
11 CS	426	0.24	5.98	0.59	0.04	0.51	1.59	376	37
12 LM	430	0.09	1.77	0.49	0.05	0.15	0.71	249	69
14 LM	431	0.12	2.14	0.35	0.05	0.18	0.66	324	53
15 CS	427	0.29	5.61	0.50	0.05	0.49	1.39	403	35
16 CS	426	0.20	4.72	0.48	0.04	0.41	1.39	339	34

<u>Explanation of column headings:</u>

Sample: Sample number (see Appendix C)
Lithofacies: LM = Lime mudstone; CS = Calcareous shale
Tmax: Temperature index, degrees C
S1: Free hydrocarbons, mg HC/g of rock
S2: Residual hydrocarbon potential (mg HC/g of rock)
S3: CO produced from kerogen pyrolysis (mg CO /g of rock)
PI: S1/S1 + S2 (transformation index)
PC*: 0.083 (S1 + S2)
TOC: Total organic carbon, weight percent
Hyd Ind: Hydrogen index, mg HC/g organic carbon
Oxy Ind: Oxygen index, mg CO /g organic carbon

Table 4. Results of Rock-eval pyrolysis on Lombard Limestone samples. Analyses made at Tenneco Oil Laboratories.

STANDARDS FOR HYDROCARBON SOURCE-ROCK EVALUATIONS

Maturation Level	Spore Color Index	Vitrinite R_o	Probable Hydrocarbon
Immature	1 (Yellow -Stains)	< 0.55	Gas
Transitional	2 (Yellow Brown)	0.55 - 0.7	Gas & Minor Oil
* Mature	3 (Brown)	0.7 - 1.0	Gas & Oil
Very Mature	4 (Dark Brown)	1.0 - 1.5	Wet Gas/Condensate
Advanced	5 (Dk.Brown to Black)	> 1.5	Gas

Total Organic Carbon (T.O.C.) (% of Rock)

	Shales	Carbonates
Poor	< 0.5	< 0.2
Fair	0.5 - 1.0	0.2 - 0.5
Rich	1.0 - 2.0	0.5 - 1.0
Very Rich	> 2.0	> 1.0

Extractable Hydrocarbons (H.C.) (ppm. of Rock)

	Shales	Carbonates
Poor	< 500	< 100
Fair	500 - 1000	100 - 500
Rich	1000 - 2000	500 - 1000
Very Rich	> 2000	> 1000

Sapropelic (% of T.O.C.)

Poor Primary Oil - Migration Potential	< 40
Good Primary Oil - Migration Potential	> 40

Kerogen Content (Humic, Exinite, Sapropelic) (ppm. of Rock)

Poor	< 2000
Fair	2000 - 5000
Rich	5000 - 10,000
Very Rich	> 10,000

Inertinite (INR.) (% of T.O.C.)

Generates no hydrocarbons. Analyzed due to inclusion in total organic carbon analysis.

Figure 57. List of standards for petroleum source rock analyses used in this report (used with permission of Tenneco Oil Company).

fresh kerogen contamination (J. H. Ruffin, written communication, 1985). The spore/pollen color values, therefore, are considered to more accurately reflect the thermal maturation of the Lombard rocks.

Analysis of these samples by pyrolysis techniques also suggests moderate burial and moderate temperatures. As shown on Table 4, S_2 values (fraction of the original organic matter available for hydrocarbon generation) exceed S_1 values (fraction of the original organic matter already transformed to hydrocarbons) in all cases. Increased burial and/or elevated temperatures cause S_1 values to increase at the expense of decreasing S_2 values (Barker, 1980). Thus, the marked dichotomy between S_2 and S_1 values, which range from (S_2:S_1) 14:1 to 24:1, argue against deep burial and/or exposure to high temperatures.

The total organic carbon content of these rocks ranges from poor to very rich based on the carbonate standard, but most display a sufficient organic richness for source bed potential. Comparison of the average total organic carbon content in the lime mudstones (average TOC = 0.48 percent) and calcareous shales (average TOC = 1.46 percent), however, reveals a striking difference. The latter rocks contain, on average, almost three times the amount of total organic carbon found in the former rocks.

In congruence with the high total organic carbon values in the calcareous shales, the hydrocarbon content in the shales is very rich, averaging 2,383 ppm. The extractable hydrocarbon content in the lime mudstone, however, is generally zero, although a few samples contain enough bitumens to assign them a rich to very rich classification (table 3). Spore/pollen color and vitrinite reflectance values indicate that the Lombard has not experienced an unfavorably high thermal history. The low hydrocarbon content, therefore, is probably the result of oxidizing conditions at the surface (J. H. Ruffin, written communication, 1985). Moderate to high total organic carbon values in rocks with no measurable hydrocarbons substantiate this hypothesis (table 3).

Sapropelic (amorphous) kerogen is dominant, followed by humic and land exinite fractions, respectively. Eight of the fourteen samples containing measurable kerogen are rich or very rich with respect to sapropelic kerogen. The humic and land exinite fractions are insignificant in quantity, making up less than ten percent of the total kerogen content in all but one sample (table 3). Sapropelic kerogen is chiefly derived from biodegradation of the rich lipid and protein residues from the exinite fraction (primarily planktonic marine algae)(J. H. Ruffin, written communication, 1985; Tissot and Welte, 1978). This hydrogen-rich kerogen is a major source of oil upon subjection to thermal catagenesis. A minimum concentration of 40 percent sapropelic matter is required to generate enough oil to initiate primary migration. The sapropelic kerogen content, which generally exceeds 80 percent in the Lombard carbonates, signifies that sufficient quantities of sapropelic matter are present to induce this process.

Calculation of the hydrogen and oxygen indices obtained from pyrolysis analyses suggest that some of the organic matter (kerogen) in the Lombard has a continental origin. There is a good correlation between the hydrogen index and atomic H/O ratio, and between the oxygen index and atomic O/C ratio, respectively. This correlation facilitates the plotting of hydrogen index values against oxygen index values on a van Krevelen diagram (Tissot and Welte, 1978). The Lombard values plot midway between the type-II and type-III kerogen evolution paths (fig. 58). Type-II kerogen is dominated by sapropelic matter, predominantly derived from marine planktonic matter deposited in a reducing environment. Type-III kerogen is derived chiefly from continental plants and, therefore, contains substantially more humic matter than type-II kerogen (Tissot and Welte, 1978). The samples from both Lombard lithofacies plot closer to the type-II kerogen evolution path than to the type-III path, suggesting a predominance of marine organic matter input. In addition, the calcareous shale lithofacies kerogen values plot closer to the type-II evolution path than the lime mudstone lithofacies values (fig. 58). This may reflect deposition farther offshore, reduced input of continental plant material, or loss of the continental plant matter close to shore. The presence of sufficient humic material to slightly skew the Lombard kerogen field toward the type-III evolution path may be the result of the epicontinental position of the Lombard sea.

The thermal maturity, total organic carbon content, and hydrocarbon content indicate that these rocks were rich to very rich oil source rocks at some time when they were sufficiently buried (J. H. Ruffin, written communication, 1985). Determination of the genetic potential of the samples, however, suggests that the capacity of the Lombard to generate additional hydrocarbons is

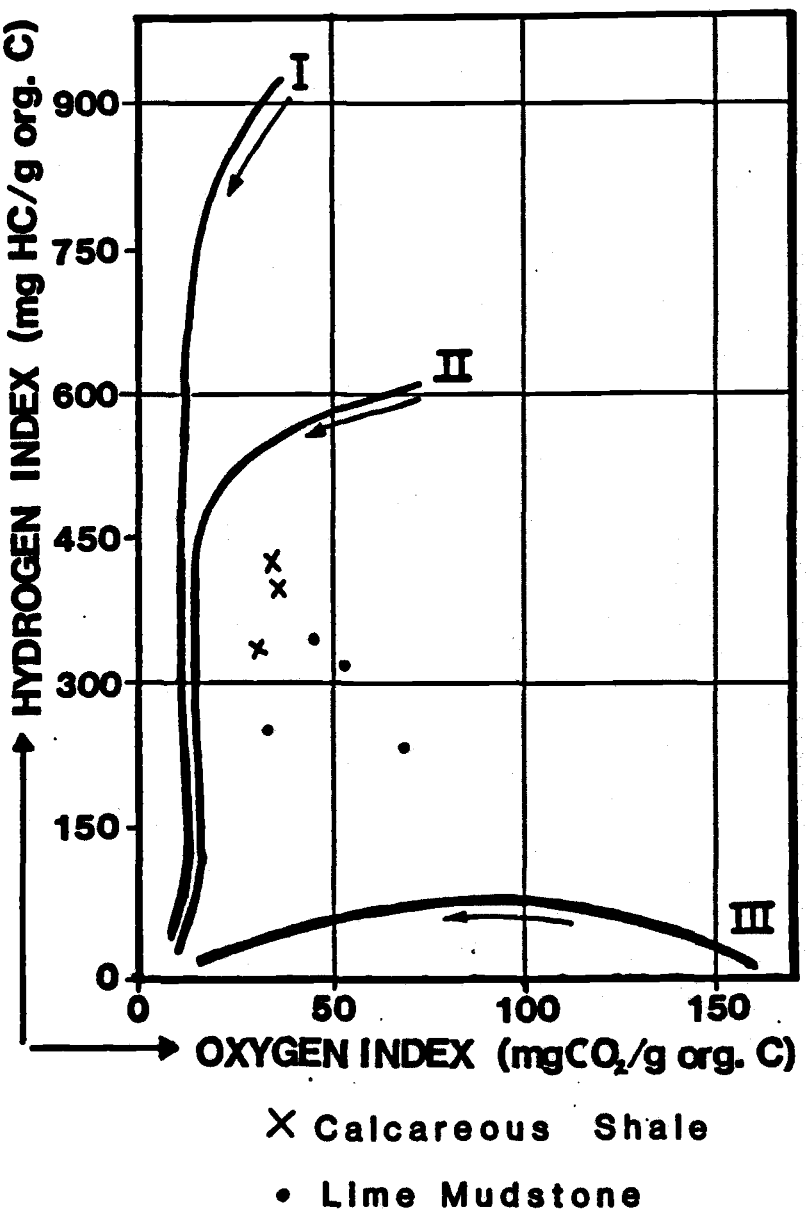


Figure 58. Classification of source rock kerogen types based on hydrogen and oxygen indices. Kerogen evolution paths from Tissot and Welte (1984). Lombard samples plot midway between Type-II and Type-III kerogen evolution paths, suggesting the presence of both sapropelic and humic types of kerogen. See Table 4 for raw data.

moderate for both lithofacies, based on the standards given by Tissot and Welte (1978; fig. 59). The average genetic potential for the lime mudstones is 2.56 kg HC/ton of rock, while the calcareous shales yield an average of 5.16 kg HC/ton of rock (fig. 59). On the basis of these values, the Lombard should be taken to have at least a moderate source rock potential.

GENETIC POTENTIAL

Sample Number	Lithofacies	S1 (mg/g)	S2 (mg/g)	S1 + S2 (kg/t)
6	Lime mudst.	0.15	3.02	2.88
7	Lime mudst.	0.26	3.67	3.57
11	Calc. shale	0.24	5.98	5.65
12	Lime mudst.	0.09	1.17	1.69
14	Lime mudst.	0.12	2.24	2.05
15	Calc. shale	0.29	5.61	5.36
16	Calc. shale	0.20	4.72	4.47

S1: Free hydrocarbons, mg HC/g of rock
S2: Residual hydrocarbon potential, mg HC/g of rock
S1 + S2: Genetic potential, kg HC/ton of rock

Grade classification
(from Tissot and Welte, 1978)

<2 kg/t (<2000 ppm) = no oil; some gas potential
2 to 6 kg/t (2000-6000 ppm) = moderate source rock
>6 kg/t (>6000 ppm) = good source rock

Figure 59. Evaluation of genetic potential of selected samples from the Lombard Limestone.

CONCLUSIONS

The Kibbey Formation and Lombard Limestone reflect middle Meramecian thorugh late Chesterian deposition in an intermittently silled trough in southwestern Montana. Kibbey sedimentation was initiated when the Big Snowy sea transgressed across the Mission Canyon karst plain in response to subsidence of the inner cratonic platform and/or eustatic rise in sea level in middle Meramecian time. The Kibbey Formation is divisible into two lithofacies, or units. The lower unit consists predominantly of silty and sandy dolostones deposited on an upper intertidal to lower supratidal (mud flat) environment. Calcite- and dolomite-cemented quartz arenites, deposited in a lower shoreface to lower intertidal (sand flat) environment, constitute the upper unit of the Kibbey.

Lombard sedimentation began at the study area in early late Meramecian time as a result of (1) rapid subsidence of the southwestern half of the Snowcrest trough, (2) the cessation of clastic input into the basin, and/or (3) northeastward migration of the Kibbey shoreface. Four lithofacies are recognized in the Lombard in the Snowcrest Range (plate 3). These four lithofacies, in ascending stratigraphic order, are: (1) the lime mudstone lithofacies, dominated by sponge spicules and ostracode debris, reflecting quiet, dysaerobic marine conditions below normal wave base; (2) fossiliferous wackestone-packstone lithofacies, containing a diverse and abundant shelly fauna representing agitated, well oxygenated, silt-free marine conditions above normal wave base; (3) calcareous shale lithofacies characterized by detrital phosphatic pellet-rich intervals, a paucity of bioclastic debris, and no bioturbation, indicative of deep, anoxic marine sedimentation below the pycnocline; and (4) the dolomitic lime mudstone lithofacies, reflecting slightly increased oxygen levels at the bottom which allowed benthic infauna to thrive, but inhibited establishment of a shelly fauna.

Analysis of the intertonguing relationships of the lime mudstone and fossiliferous wackestone-packstone lithofacies, and isopach data of the Lombard, suggest that subsidence in the southwestern half of the Snowcrest trough exceeded that in the northeastern half throughout most of Lombard time (figs. 52, 53). Correlation of the Kibbey and Lombard lithofacies with time-equivalent units to the west and east reveals the significant impact of differential episodic subsidence of the inner and outer cratonic platforms on the type and rate of sedimentation. Seven major tectono-sedimentary events are recognized in the southwestern Montana and east-central Idaho region:

1. Late middle Meramecian: Kibbey Formation deposited in the subsiding Snowcrest trough behind an upbuilding carbonate bank complex (Scott Peak Formation) on the outer cratonic platform (plate 4-A).

2. Late Meramecian: Continued upbuilding of the bank and/or tectonic elevation of the outer cratonic platform produced a moderate sill at the mouth of the Snowcrest trough (plate

4-B). Episodic differential sedimentation at the northeastern end of the trough promoted cyclic progradation and retrogradation of the shallow water limestones (fossiliferous wackestone-packstone lithofacies) over deep water limestones (lime mudstone lithofacies). Subsidence in the southwestern part of the trough continued to exceed sedimentation, resulting in deposition of a thick lime mudstone lithofacies sequence.

3. Early Chesterian: Rapid subsidence of the outer cratonic platform caused drowning of the bank complex (Scott Peak Formation) and initiation of calcareous shale (South Creek Formation) sedimentation in its place (plate 4-C). Decreased subsidence rates in the Snowcrest trough combining with improved basin circulation enhanced proliferation of the shallow water shelly fauna. Rapid southwest-directed progradation of the fossiliferous wackestone-packstone lithofacies occurred basinwide. Shoaling locally resulted in the development of swamps, which are reflected in the Lombard as thin coal seams. Kibbey and Otter deposition began at this time in central Montana when the Big Snowy sea transgressed over the Lombard arch into the subsiding Big Snowy basin.

4. Early late Chesterian: Slow subsidence rates and ideal conditions for carbonate-secreting epifauna in the trough caused continued progradation of the shallow water limestones

at least as far as the present-day southwesternmost Montana area (plate 4-D). Subsidence of the outer cratonic platform continued to exceed sedimentation.

5. Middle late Chesterian: Uplift of the outer cratonic platform promoted re-establishment of a carbonate bank complex (Surrett Canyon Formation), creating a silled basin in the Snowcrest trough (plate 4-E). Rapid subsidence, greater than during previous subsidence events on the inner cratonic platform, and the development of anoxic bottom conditions in the central and southwestern parts of the Snowcrest trough resulted in the deposition of calcareous shale. Shallow water limestones were deposited in the northeastern part of the trough where sedimentation was slightly greater or equal to subsidence.

6. Middle late Chesterian: Decreased subsidence and/or slight uplift of the southwestern and central parts of the Snowcrest trough, and destabilization of the pycnocline caused a change in bottom conditions permitting the return of a benthic infauna. The carbonate bank at the mouth of the trough continued to act as a submerged sill, however, causing dysaerobic benthic conditions inimical to the development of a shelly fauna in the present-day Snowcrest Range area (plate 4-F). The gradational transition from the calcareous shale to the dolomitic lime mudstone lithofacies records this progressive change in depositional environment. In the

vicinity of the Montana-Idaho border shallow water conditions prevailed, extending westward to the bank complex on the outer cratonic platform (plate 4-F).

7. Latest late Chesterian: Regional uplift in central and southwestern Montana caused complete withdrawl of the Big Snowy sea to a position between the present-day Snowcrest Range area and Montana-Idaho border. Clastic material shed from the elevated landmass to the east was deposited in shallow lagoons and estuaries in southwesternmost Montana (Conover Ranch Formation; plate 4-G). Subsequent subsidence in the trough resulted in overstepping of the slightly(?) eroded Lombard by the Conover Ranch as the sea transgressed to the east.

The lime mudstone and calcareous shale lithofacies of the Lombard in the Snowcrest Range display a moderate or good petroleum source rock potential, based on geochemical analyses. Favorable traps for hydrocarbon accumulation may be present in southwesternmost Montana as a result of structural overprinting of Laramide and Sevier thrust faulting, and in the Snowcrest region in association with the inferred sub-Snowcrest Range thrust fault. Such traps at depth, which incorporate Lombard mudstones and shales may be alluring targets to exploration geologists.

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APPENDICES

APPENDIX A: MEASURED SECTIONS

The bed thickness, splitting habit, and bedding-lamination terminology incorporated in the following measured sections is from Collinson and Thompson (1982), which represents modifications of earlier terminology of Campbell (1967) and Reineck and Singh (1973). This terminology is illustrated on the following page (fig. 60). Additional modification includes the description of bed contacts and splitting habit as planar, slightly undulatory (<1/8" total relief), and undulatory (>1/8" total relief), to supplant the term "wavy", used by Collinson and Thompson (1982). All color descriptions of fresh rock surfaces are of moistened surfaces. The petroliferous odor of the rock, described as absent, very weak, weak, moderate, strong, and very strong, refers to the odor upon striking a fresh surface with a hammer.

Coral and brachiopod identifications were made by Bill Sando and Tom Dutro, Jr., respectively, of the U. S. Geological Survey.

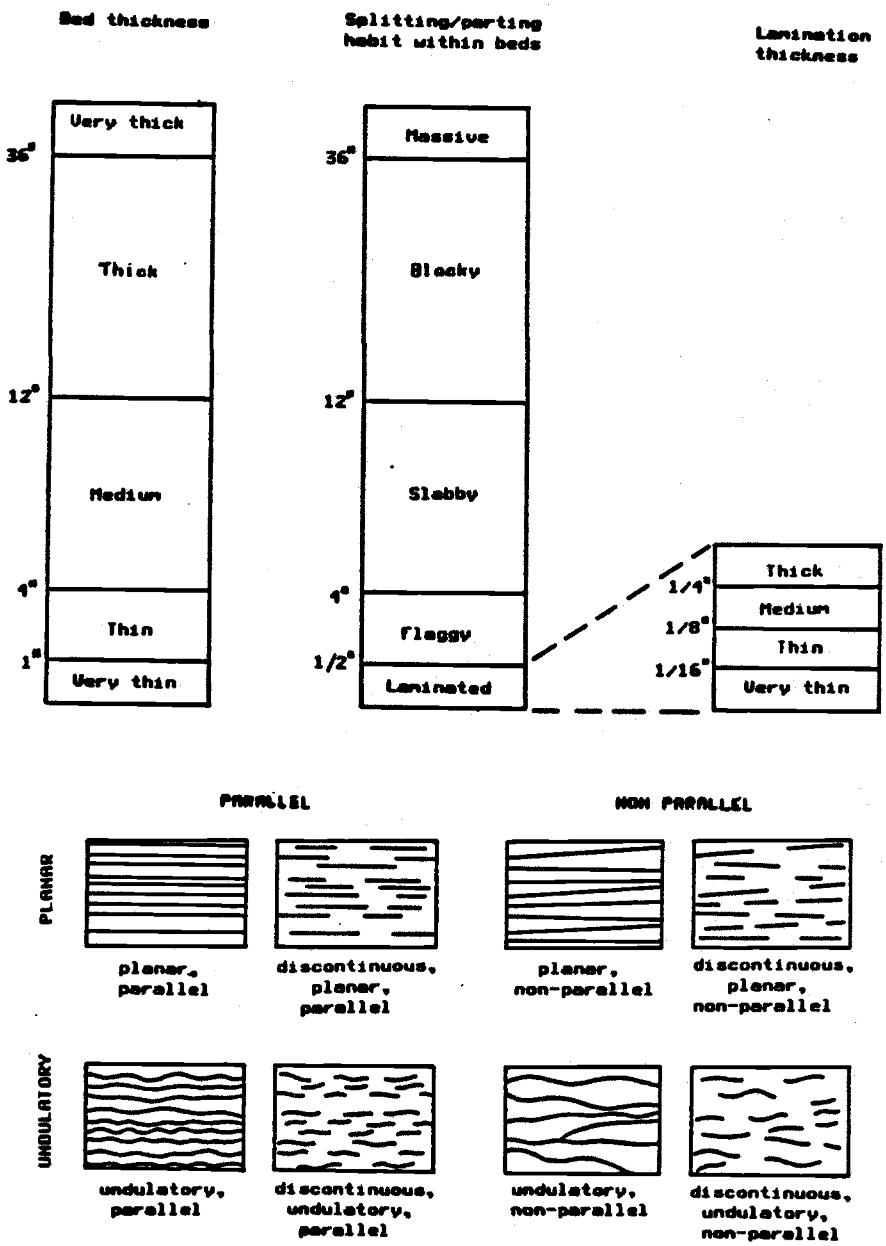


Fig. 60. Terminology for thickness of beds and laminations, for splitting and parting habit of units within beds, and for bedding-lamination terminology (modified from Collinson and Thompson, 1982).

I. RED ROCK RIVER SECTION

SW 1/4, NW 1/4, section 28, T. 13 S., R. 7 W., Henry Gulch Quadrangle, U.S.G.S. 7.5 minute series. Lombard Limestone section measured from west to east, beginning at uppermost Mission Canyon Limestone exposure, approximately 2,640 feet west-northwest of knob in the center of section 28. The lowermost covered interval probably includes uppermost Mission Canyon Limestone, Kibbey Sandstone, and lowermost Lombard Limestone. This covered interval is characteristic throughout the southernmost end of the Snowcrest Range.

To reach this location, travel due east out of Lima on the road to Lima reservoir. The road turns due north at approximately 4.8 miles from Lima, then turns east-southeast at 6.2 miles (by a gravel pit). Travel an additional 1.4 miles east to a dirt road which runs north onto a grassy bench slightly higher in elevation than the gravel road. The knob is located approximately 0.6 road miles up this dirt road, on the east side of the road.

Exposure quality is poor to fair. Silty limestone intervals are characteristically very poorly exposed or covered, but the near-vertical attitude of the beds limits contamination by float from adjacent beds, permitting relatively accurate measurement and lithological identification (by trenching). The stratigraphically lowest exposure of the Lombard Limestone is located in the gully, immediately east of the dirt road, where it changes from a north-south to a northeast-southwest trend.

Unit	lithology	ft.
113	COVER: Sandy soil, grayish orange (10 YR 7/4) to yellowish orange (10 YR 7/6); scattered sandstone float of same color as soil; probably basal Amsden sandstone; transition with subjacent silty limestone soil occurs over a five foot interval	unm.
112	COVER: Silty mudstone float and soil, medium gray (N5)	42±5
111	BRYOZOAN PACKSTONE: Olive gray (5 Y 4/1), weathers to medium gray (N5); finely crystalline, trepostomous and fenestrate bryozoans, disarticulated brachiopods, echinoid ossicles and partial stems, trilobite fragments, ostracodes, small corals (<u>Siphonophyllia</u> sp.), gastropods; fossils randomly distributed, most parallel bedding; weak petroliferous odor; moderately fractured, subdued rib-former	2
110	COVER: Gray soil, Silty mudstone chips	3
109	BRYOZOAN-BRACHIOPOD PACKSTONE: Olive gray (5 Y 4/1), weathers to medium light gray (N6); finely crystalline, crudely bedded; thick to very thick beds with many randomly spaced, irregular fractures; trepostomous and fenestrate bryozoans, disarticulated brachiopods, echinoid ossicles and partial stems, gastropods, trilobite fragments; fossils randomly distributed, most parallel crude bedding; weak to absent petroliferous odor; rib-former	16
108	COVER: Gray soil with silty mudstone chips; grassy	3.5
107	SPARSELY FOSSILIFEROUS WACKESTONE: Medium olive gray (5 Y 5/1), weathers to moderate yellowish brown (10 YR 5/4); microcrystalline; flaggy; echinoid and bryozoan fragments, disarticulated brachiopods; fossils randomly oriented and distributed; strong petroliferous odor	1
106	COVER: Gray soil with few mudstone chips	6
105	MUDSTONE: Dark gray (N3), weathers to medium gray (N5); microcrystalline; slightly	

silty; very poorly exposed..........................1

104 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to pale grayish orange (10 YR 8/4); microcrystalline; echinoid fragments, gastropods, disarticulated and whole pelecypods; fossils randomly oriented and distributed; many vertical fractures; moderate petroliferous odor...............2

103 SILTY MUDSTONE: Dark gray (N3), weathers to medium gray (N5); microcrystalline; sharp upper and lower contacts; poorly exposed............3

102 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to pale grayish orange (10 YR 8/4); microcrystalline; no discernable bedding; echinoid fragments, disarticulated pelecypods(?); fossils randomly oriented and distributed; abundant vertical fractures; weak petroliferous odor; very subdued rib-former..2

101 COVER: Pale orangish gray (10 YR 8/4) to light gray (N7) soil; scattered mudstone chips............6

100 SPARSELY FOSSILIFEROUS WACKESTONE: Medium olive gray (5 Y 5/1), weathers to moderate yellowish brown (10 YR 5/4); flaggy; microcrystalline; echinoid and bryozoan fragments, gastropods, disarticulated and whole pelecypods; fossils randomly oriented and distributed; abundant vertical fractures; weak petroliferous odor; sharp contact with unit 99...............................1.5

99 MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; slightly silty; very poorly exposed; strong petroliferous odor..............................3

98 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to moderate yellowish brown (10 YR 5/4); microcrystalline; flaggy; no discernable bedding; echinoid and bryozoan fragments, whole and disarticulated pelecypods, disarticulated brachiopods(?), gastropods; fossils randomly oriented and distributed; horizontal burrows(?); many vertical fractures; moderate petroliferous odor; very subdued rib-former; sharp planar contact with unit 99........................2

97 COVER: Gray soil; grassy; few silty mudstone chips..3

96 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; parallel, slightly undulatory, laminated to flaggy splitting habit; disarticulated brachiopods, echinoid debris, ostracodes, gastropods; fossils randomly oriented and distributed; extensively fractured; moderate petroliferous odor; few chert nodules; rib-former; sharp, slightly undulatory contact with unit 96...................................2

95 MUDSTONE: Dark gray (N3); weathers to light olive gray (5 Y 6/1); microcrystalline; very poorly exposed....................................1.5

94 COVER: Gray soil; grassy..............................10.5

93 MUDSTONE: Dark gray (N3), weathers to medium gray (N5); microcrystalline; very poorly exposed; sharp, planar to slightly undulatory contact with unit 92.....................1

92 BRACHIOPOD WACKESTONE: Olive gray (5 Y 4/1), weathers to light olive gray (5 Y 4/1) to very pale orange (10 YR 8/2); microcrystalline; very thick bed with minor parallel, undulatory, slabby to locally flaggy splitting habit; whole and disarticulated brachiopods (Productids, <u>Chonetes</u> sp.?), bryozoan and echinoid debris; fossils randomly oriented and distributed; brachiopods stand with slight relief on weathered surface; many siliceous stringers; strong fetid odor; pronounced rib-former; sharp, planar to slightly undulatory upper and lower contacts.........5

91 MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; slightly silty; very poorly exposed...........................2

90 FOSSILIFEROUS WACKESTONE: Brownish gray (5 YR 4/1), weathers to medium olive gray (5 Y 5/1); microcrystalline; flaggy; random, small sparry calcite patches; abundant bryozoan fragments, disarticulated and broken brachiopods, echinoid ossicles and fragments; fossils randomly oriented and distributed; extensively fractured; few small chert pods; very strong petroliferous

odor; pronounced rib-former; sharp, slightly undulatory upper and lower contacts..................1

89 MUDSTONE: Dark gray (N3), weathers to light gray (N7) to pale grayish orange (10 YR 8/4); microcrystalline; slightly silty; poorly exposed, largely soil-covered.........................2.5

88 FOSSILIFEROUS WACKESTONE: Brownish gray (5 YR 4/1), weathers to medium light gray (N6); microcrystalline; irregular, flaggy splitting habit; abundant ramose and few fenestrate bryozoan fragments, disarticulated and broken brachiopods, echinoid ossicles, gastropods; fossils randomly oriented and distributed; few chert stringers; very strong petroliferous odor; pronounced rib-former; sharp, planar to slightly undulatory contact..........................4

87 COVER: Gray soil; silty mudstone float..................3.5

86 FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to light gray (N7); microcrystalline; flaggy; fossil hash of broken brachiopods, echinoids, bryozoans, pelecypods(?), ostracodes; fossils randomly oriented and distributed; strong petroliferous odor....................................1

85 COVER: Gray soil; silty mudstone float.................3

84 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to medium brownish gray (5 YR 5/1); microcrystalline; crudely bedded; echinoid ossicles and fragments, brachiopods, bryozoans, ostracodes; also corals (<u>Siphonophyllia excentrica</u> (Meek), and <u>Siphonophyllia</u> sp.), gastropods; fossils randomly oriented and distributed; burrows(?); moderate petroliferous odor; subdued rib-former; sharp contact with unit 83..........................2.5

83 MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; undulatory, laminated to flaggy splitting habit; no discernable bedding; slightly to moderately silty; strong fetid odor; poorly exposed.............3.5

82 FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to medium light gray (N6); microcrystalline; irregular, flaggy splitting habit; disarticulated and

broken brachiopods (including Neospirifer praenuntius Easton), pelecypods(?), and echinoids; also corals (Siphonophyllia sp.), ramose bryozoan debris, ostracodes; fossils randomly oriented and distributed; bioturbated; strong petroliferous odor; subdued rib-former; sharp, planar contact with unit 83.................................3

81 COVER: Gray soil; silty mudstone float.................4

80 SPARSELY FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; small disarticulated brachiopods, ostracodes, echinoid debris; fossils randomly oriented and distributed; burrows; moderate petroliferous odor; very subdued rib-former; sharp, undulatory contact with unit 79...............1

79 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; no discernable bedding; undulatory, non-parallel, laminated to flaggy splitting habit; slightly silty; small, disarticulated brachiopods, echinoid ossicles, indeterminate fossil fragments; fossils parallel bedding, randomly distributed; very strong petroliferous odor; moderately well exposed; sharp, undulatory upper and lower contacts.............................2

78 SPARSELY FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; echinoid debris, small disarticulated brachiopods, ostracodes(?); fossils randomly distributed,most parallel bedding; moderate petroliferous odor; subdued rib-former; sharp, undulatory upper and lower contacts...........2

77 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; no discernable bedding; undulatory, non-parallel, laminated to flaggy splitting habit; slightly silty; small, disarticulated brachiopods, echinoid debris, ostracodes; fossils randomly distributed, most parallel bedding ; strong petroliferous odor; moderately well exposed; sharp, undulatory to slightly undulatory upper and lower contacts.............................4

76 SPARSELY FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; flaggy; small disarticulated brachiopods (including Productids), echinoid debris, ostracodes; fossils randomly distributed, most subparallel to bedding; horizontal burrows; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 77.................................2

75 COVER: Gray soil; silty mudstone float.................8

74 SPARSELY FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; undulatory, non-parallel, laminated to flaggy splitting habit; slightly silty; few ostracodes, disarticulated brachiopods, echinoid debris; fossils randomly distributed, parallel bedding; strong petroliferous odor; poorly exposed; sharp, slightly undulatory contact with unit 73.................................1

73 SPARSELY FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; flaggy to slabby; small, disarticulated brachiopods, echinoid ossicles and partial stems, ostracodes, indeterminate mollusk fragments; fossils randomly distributed, most subparallel bedding; moderate petroliferous odor; subdued rib-former............................3

72 COVER: Gray soil; grassy; silty mudstone float..........5

71 SPARSELY FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; echinoid fragments, small disarticulated brachiopods and pelecypods(?); fossils randomly distributed, most parallel bedding; moderate petroliferous odor; subdued rib-former; sharp, planar to slightly undulatory contact with unit 70.....................1

70 SPARSELY FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; undulatory, non-parallel, laminated to flaggy splitting habit; ostracodes(?), echinoid fragments, small disarticulated brachiopods; fossils randomly distributed, parallel bedding; moderate petroliferous odor; poorly exposed; sharp,

slightly undulatory upper and lower contacts.........2

69 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; slabby; disarticulated brachiopods (including *Ovatia* cf. *O. muralis* Gordon, *Limipecten* cf. *L. otterensis* Easton) and pelecypods(?), ostracodes, echinoid ossicles and fragments, indeterminate orthoconic nautiloid mold; most fossils parallel bedding, randomly distributed; burrows; strong fetid odor; subtle rib-former; sharp, slightly undulatory upper and lower contacts.................3

68 SPARSELY FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; undulatory, non-parallel, laminated to flaggy splitting habit; many dark gray wisps on weathered surface; few small, disarticulated brachiopods, ostracodes, echinoid fragments; fossils randomly distributed, most parallel bedding; horizontal burrows; strong petroliferous odor; sharp, slightly to moderately undulatory upper and lower contacts.................2

67 SPARSELY FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; flaggy to slabby; small, disarticulated brachiopods and pelecypods(?), echinoid ossicles and fragments, ostracodes(?); fossils randomly distributed, most parallel bedding; strong fetid odor; subdued rib-former; sharp, moderately undulatory contact with unit 68.......................................2

66 COVER: Gray soil; grassy.............................7

65 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; undulatory, parallel, laminated to flaggy splitting habit; disarticulated and broken brachiopods, echinoid ossicles; fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 64.......................................1

64 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to yellowish gray (5 Y 8/1);

microcrystalline; slabby; disarticulated and broken brachiopods, echinoid ossicles and few partial stems; fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former..............2

63 COVER: Gray to grayish orange (10 YR 7/4) soil; abundant mudstone and silty mudstone chips..8

62 FOSSILIFEROUS MUDSTONE: Medium gray (N5), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; undulatory, non-parallel to parallel, laminated to flaggy splitting habit; few disarticulated brachiopods, echinoid ossicles; fossils randomly oriented and distributed; strong petroliferous odor; subdued rib-former..............1

61 COVER: Gray soil; silty mudstone and fossiliferous mudstone chips.........................3

60 FOSSILIFEROUS MUDSTONE: Medium gray (N5), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; undulatory, non-parallel to parallel, flaggy splitting habit; echinoid ossicles, disarticulated brachiopods, ostracodes(?); fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued rib-former...2

59 COVER: Gray to grayish orange (10 YR 7/4) soil, moderately grassy; abundant silty mudstone and fossiliferous mudstone chips...........27

58 FOSSILIFEROUS MUDSTONE: Meduium dark gray (N4), weathers to light olive gray (5 Y 6/1); microcrystalline; undulatory, parallel, laminated to flaggy splitting habit; disarticulated and broken brachiopods, echinoid ossicles; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 57.....................2

57 FOSSILIFEROUS MUDSTONE: Medium dark gray (N5), weathers to yellowish gray (5 Y 8/1); microcrystalline; disarticulated brachiopods, echinoid ossicles and partial stems; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued rib-former...1

56 COVER: Gray soil; silty mudstone chips................9

55 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to light olive gray (5 Y 6/1); microcrystalline; undulatory, parallel, laminated to flaggy splitting habit; few disarticulated brachiopods, echinoid ossicles, indeterminate fossil fragments; fossils randomly distributed, subparallel to bedding; strong petroliferous odor; subdued rib-former.......................................2

54 COVER: Grayish orange (10 YR 7/4) soil; silty mudstone and fossiliferous mudstone chips; grassy...17

53 FOSSILIFEROUS MUDSTONE: Medium gray (N5), weathers to light gray (N7); microcrystalline; slabby; echinoid ossicles and partial stems, disarticulated brachiopods; fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 52....................1

52 FOSSILIFEROUS MUDSTONE: Medium gray (N5), weathers to light gray (N7); microcrystalline; no discernable bedding; undulatory, non-parallel to parallel, laminated to flaggy splitting habit; small disarticulated brachiopods, echinoid ossicles, indeterminate fossil debris; fossils subparallel bedding, randomly distributed; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with overlying unit 53, but gradational into unit 51...................3

51 FOSSILIFEROUS MUDSTONE: Medium gray (N5), weathers to light gray (N7); microcrystalline; thick bed; slabby; disarticulated brachiopods and pelecypods(?), echinoid ossicles and fragments; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; sharp, slightly undulatory contact with unit 50.......................................2

50 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to medium light gray (N6); microcrystalline; undulatory, parallel, laminated to flaggy splitting habit; few disarticulated brachiopods, echinoid ossicles; fossils randomly oriented and

distributed; strong petroliferous odor; subdued rib-former....................................1

49 COVER: Gray to grayish orange (10 YR 7/4) soil; silty mudstone chips...........................5

48 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; disarticulated and broken brachiopods and pelecypods(?), echinoid ossicles; fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former.............................1

47 COVER: Grayish orange (10 YR 7/4) soil; fossiliferous(?) mudstone and silty mudstone chips......................................6

46 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; undulatory, non-parallel to parallel, laminated to flaggy splitting habit; disarticulated brachiopods, echinoid ossicles and partial stems, ostracodes(?); fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former..2

45 COVER: Grayish orange (10 YR 7/4) soil; fossiliferous and silty mudstone chips..............8

44 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; no discernable bedding; undulatory, parallel, laminated to flaggy splitting habit; disarticulated brachiopods and pelecypods(?), echinoid ossicles and fragments; fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 43....................3

43 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; slabby; disarticulated brachiopods, echinoid ossicles and partial stems, ostracodes; fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former; sharp slightly undulatory upper and lower contacts.................1

42 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; undulatory, non-parallel to

parallel, laminated to flaggy splitting habit; disarticulated brachiopods, echinoid ossicles, ostracodes; fossils randomly oriented and distributed; strong petroliferous odor; subdued rib-former..............2

41 COVER: Grayish orange (10 YR 7/4) soil; silty mudstone and fossiliferous mudstone chips; grassy......................................12

40 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; undulatory, parallel, laminated to flaggy splitting habit; disarticulated and broken brachiopods and pelecypods(?), echinoid ossicles and partial stems, ostracodes; fossils randomly oriented and distributed; strong petroliferous odor; subdued rib-former...............2

39 COVER: Grayish orange (10 YR 7/4) soil; grassy; silty mudstone and fossiliferous mudstone chips; low-relief saddle..................89

38 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to medium gray (N5); microcrystalline; minor parallel, planar to slightly undulatory, slabby splitting habit; disarticulated brachiopods, echinoid ossicles, bryozoan fragments, gastropods; fossils randomly distributed, most subparallel to bedding, many broken; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory to locally planar contact with unit 37.................2

37 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to medium light gray (N6); microcrystalline; undulatory, non-parallel laminated to flaggy splitting habit; no discernable bedding; locally disturbed, thin to medium lamina; echinoid ossicles, few disarticulated brachiopods; fossils randomly distributed, most subparallel to bedding; strong petroliferous odor; moderately well exposed..2

36 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to medium gray (N5); microcrystalline; slabby; many echinoid ossicles, few partial stems, disarticulated brachiopods, gastropods(?), bryozoan fragments; fossils randomly oriented and distributed; moderate petroliferous odor;

subdued rib-former; sharp, slightly undulatory upper and lower contacts..................1

35 COVER: Gray soil; fossiliferous mudstone chips..4

34 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to light gray (N7); microcrystalline; non-parallel, undulatory, flaggy splitting habit; locally disturbed to slightly deformed (flame structures?), thin to medium lamina; echinoid ossicles, disarticulated brachiopods, gastropods, ostracodes; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued rib-former...........................1

33 COVER: Gray soil; fossiliferous mudstone and silty mudstone chips...............................7

32 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to medium gray (N5); microcrystalline; flaggy to slabby; echinoid ossicles and partial stems, disarticulated brachiopods, fenestrate and ramose bryozoan fragments, gastropods, foraminifera; fossils randomly oriented and distributed; moderate petroliferous odor; moderately well pronounced rib-former...............2

31 COVER: Grayish orange (10 YR 7/4) to gray soil; fossiliferous mudstone and silty mudstone chips....................................3

30 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to light gray (N7); microcrystalline; echinoid ossicles, disarticulated brachiopods, ostracodes, gastropods; fossils randomly oriented distributed; moderate petroliferous odor; very subdued rib-former...............................0.5

29 COVER: Grayish orange (10 YR 7/4) soil; silty mudstone and fossiliferous mudstone chips...10.5

28 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to medium light gray (N6); microcrystalline; parallel to locally non-parallel, undulatory, laminated to flaggy splitting habit; faint, thin to medium lamina visible on weathered surface; few echinoid ossicles, small disarticulated brachiopods, ostracodes;

fossils subparallel to bedding, locally concentrated into discrete layers, but randomly distributed in upper part of unit; moderately petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 29..............................2

27 FOSSILIFEROUS PACKSTONE: Medium gray (N4), weathers to medium gray (N5); microcrystalline; medium-bedded; planar; echinoid ossicles and partial stems; disarticulated brachiopods, ostracodes, and pelecypods(?), gastropods, trilobites, fenestrate and ramose bryozoan debris; fossils randomly oriented and distributed, many broken; moderate petroliferous odor; moderately well pronounced rib-former; sharp, slightly undulatory upper and lower contacts..3

26 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to light gray (N7); microcrystalline; no discernable bedding; parallel, undulatory, laminated to flaggy splitting habit; faint, thin to medium lamina on weathered surface; few echinoid ossicles, small disarticulated brachiopods; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued rib-former; sharp, slightly undulatory upper and lower contacts; poorly to moderately well exposed.........................6

25 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to medium light gray (N6); microcrystalline; echinoid ossicles, disarticulated brachiopods, bryozoan debris, pelecypod(?) fragments, foraminifera; fossils randomly oriented and distributed; moderate petroliferous odor; subdued rib-former................................1

24 COVER: Gray to grayish orange (10 YR 7/4) soil; silty mudstone and fossiliferous mudstone chips; grassy.............................6

23 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; undulatory non-parallel to parallel, slightly undulatory to undulatory, laminated to predominantly flaggy splitting habit; few echinoid ossicles, disarticulated brachiopods; fossils subparallel to

bedding, randomly distributed; moderate petroliferous odor; very subdued rib-former..........2

22 ECHINOID PACKSTONE: Medium dark gray (N4), weathers to yellowish gray (5 Y 8/1) to very pale orange (10 YR 8/2); microcrystalline; planar, slabby splitting habit; many echinoid ossicles and plates, few partial stems, disarticulated brachiopods and pelecypods, ostracodes, foraminifera, bryozoan debris; fossils subparallel to bedding, concentrated into very thin, discrete layers separated by extremely thin mud laminae; strong petroliferous odor; moderately well pronounced rib-former; sharp, slightly undulatory to locally planar upper and lower contacts....................................2

21 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale yellowish brown (10 YR 6/2); microcrystalline; parallel to non-parallel, undulatory, laminated to flaggy splitting habit; echinoid ossicles, disarticulated brachiopods; fossils subparallel to bedding, randomly distributed; moderate to strong petroliferous odor; very subdued rib-former; moderately well exposed; sharp, slightly undulatory upper and lower contacts..3

20 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to light brownish gray (5 YR 6/1); finely crystalline (slightly recrystallized); parallel, planar, slabby splitting habit; echinoid plates and ossicles, few partial stems, disarticulated brachiopods, ostracodes, bryozoan debris; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 21.....................4

19 COVER: Grayish orange (10 YR 7/4) soil; silty mudstone and fossiliferous mudstone chips...........9

18 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to yellowish gray (5 Y 8/1); microcrystalline; parallel, planar to slighty undulatory, slabby splitting habit; echinoid ossicles and plates, disarticulated brachiopods and pelecypods(?), gastropods; fossils subparallel to bedding; moderate

petroliferous odor; subdued rib-former; sharp, slightly undulatory lower contact with unit 17....................................3

17 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to light gray (N7); microcrystalline; non-parallel to predominantly parallel, undulatory, laminated to flaggy splitting habit; few echinoid ossicles, disarticulated brachiopods; fossils subparallel to bedding; strong petroliferous odor; very subdued rib-former; sharp, planar to locally slightly undulatory contact with unit 16..1

16 FOSSILIFEROUS PACKSTONE: Medium dark gray (N4), weathers to yellowish gray (5 Y 8/1); microcrystalline; flaggy to slabby; echinoid ossicles, partial stems, disarticulated brachiopods and pelecypods(?), ostracodes, gastropods, bryozoan(?) debris; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued rib-former..................................2

15 COVER: Grassy slope; trenching indicates dark gray (N3); non-fossiliferous to sparsely fossiliferous mudstone.............................96

14 FOSSILIFEROUS MUDSTONE: Very pale yellowish brown (10 YR 7/2), weathers to light gray (N7); microcrystalline; thick bed; random, irregular horizontal fractures; echinoid ossicles, disarticulated brachiopods, gastropods; fossils randomly oriented and distributed; horizontal burrows; strong fetid odor; subdued rib-former......................2

13 SPARSELY FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to yellowish gray (5 Y 8/1); microcrystalline; thick bed; few vertical fractures; few echinoid ossicles and partial stems, small disarticulated and broken brachiopods, ostracodes; fossils randomly oriented and distributed; many dark carbonaceous(?) wisps subparallel to bedding; burrows(?); moderate petroliferous odor; silty mudstone partings separate underlying and overlying units; sharp, slightly undulatory upper and lower contacts......................................3

12 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to pale grayish orange (10 YR 8/4); microcrystalline; non-parallel, planar to slightly undulatory, flaggy splitting habit; echinoid ossicles and fragments, disarticulated brachiopods, ostracodes, indeterminate grazing(?) trails on splitting planes; fossils randomly oriented and distributed; moderate petroliferous odor; sharp, planar contact with underlying unit 11..............................1

11 SILTY FOSSILIFEROUS MUDSTONE: Brownish gray (5 YR 4/1), weathers to light olive gray (5 Y 6/1); microcrystalline; abundant quartzose silt; non-parallel, planar flaggy to predominantly laminated splitting habit; ostracodes, few echinoid ossicles and brachiopod fragments; most fossils parallel to bedding, randomly distributed, rarely locally clustered; horizontal burrows; gradational transition with underlying unit 10...2

10 FOSSILIFEROUS-PELLETAL MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light olive gray (5 Y 6/1); microcrystalline; parallel, planar to slightly undulatory, flaggy splitting habit; ostracodes, echinoid ossicles and fragments, gastropods; abundant pellets; most fossils parallel to bedding, randomly distributed; horizontal burrows(?); very subdued rib-former...........................5

9 COVER: Light brownish gray (5 YR 6/1) soil; silty mudstone and fossiliferous mudstone chips...20

8 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to very light gray (N8); microcrystalline; medium beds with parallel to non-parallel, planar, flaggy splitting habit; silty mudstone partings between beds; faint parallel, very thin laminae locally; whole and disarticulated brachiopods and pelecypods, echinoid ossicles, gastropods; fossils subparallel to bedding; few black (carbonaceous?) wisps; few small, grayish orange (10 YR 7/4), augen-shaped chert nodules; very subdued rib-former; sharp, planar to slightly undulatory contact with unit 7.................................3

7 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to yellowish gray (5 Y 7/2); microcrystalline; parallel, planar to slightly undulatory, flaggy splitting habit; echinoid ossicles, few partial stems, few whole pelecypods, ostracodes; fossils randomly oriented and distributed, stand with moderate relief on weathered surface; horizontal and subhorizontal burrows; strong petroliferous odor; subdued rib-former; sharp, slightly undulatory contact with unit 6.....................3

6 FOSSILIFEROUS MUDSTONE: Black (N1), weathers to very light gray (N8); microcrystalline; medium beds with parallel, planar to slightly undulatory, flaggy to slabby splitting habit, several thin fissile intervals (1-2 inches thick); faint, very thin, parallel laminations locally visible on weathered surface; ostracodes, few echinoid ossicles, few disarticulated pelecypods; fossils parallel bedding, randomly distributed; few grayish orange (10 YR 7/4) augen-shaped chert nodules; few black, carbonaceous(?) wisps subparallel to bedding; very strong petroliferous odor; very subdued rib-former; sharp, slightly undulatory contact with unit 5...5

5 CALCAREOUS SHALE: Black (N1), weathers to light gray (N7); microcrystalline; silty; parallel, planar, fissile to laminated splitting habit; very thin, parallel laminae; non-fossiliferous(?); very strong petroliferous odor; moderately well exposed; sharp, slightly undulatory contact with unit 4.......................................2

4 FOSSILIFEROUS MUDSTONE: Grayish black (N2), weathers to very light gray (N8); microcrystalline; thin to medium beds with parallel, slightly undulatory to planar, fissile to laminated splitting habit, alternating with medium beds with a parallel, slightly undulatory to planar, flaggy to blocky splitting habit; fissile to laminated interbeds progressively decrease in thickness upsection; few echinoid ossicles and fragments, ostracodes, disarticulated pelecypods; fossils parallel to bedding, randomly distributed; few grayish orange (10 YR 7/4), augen-shaped

chert nodules; very subdued rib-former; sharp, slightly undulatory contact with unit 3..24

3 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; thin to medium beds with parallel, slightly undulatory, fissile to laminated splitting habit alternating with medium beds with parallel, planar to slightly undulatory, flaggy to blocky splitting habit; very thin, parallel laminae locally visible on weathered surface; alternating bed types subequal in number; few echinoid ossicles and fragments, whole and disarticulated brachiopods and pelecypods, few gastropods; most fossils subparallel to bedding, randomly distributed, stand with slight relief on weathered surface; many black, carbonaceous(?) wisps, <u>many</u> large (up to 8 inches long), grayish orange (10 YR 7/4), augen-shaped chert nodules; moderate to strong petroliferous odor; very subdued rib-former; sharp, slightly undulatory contact with unit 2......................7

2 FOSSILIFEROUS MUDSTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; thin to medium beds with parallel, planar to moderately undulatory, fissile to laminated to locally flaggy splitting habit, alternating with medium beds with parallel, planar to slightly undulatory, flaggy to blocky splitting habit; fissile to laminated interbeds progressively decrease in thickness in upper third of unit; disarticulated ostracodes and pelecypods, echinoid and gastropod fragments; fossils parallel bedding, randomly distributed; rare, small, grayish orange (10 YR 7/4), augen-shaped chert nodules; very subdued rib-former.............19

1 COVER: gray to grayish orange (10 YR 7/4) soil; narrow zone of admixed grayish orange (10 YR 7/4) to moderate yellowish brown (10 YR 5/4) soil in lower 110 20 feet; silty, non-fosslilferous, and fossiliferous mudstone chips; grassy; this interval is covered throughout the southwestern end of the range...<229

TOTAL: 894.0 feet

II. CLOVER DIVIDE SECTION

NW 1/4, SE 1/4, and SE 1/4, NW 1/4, section 23, T. 12 S., R. 6 W., Whiskey Spring quadrangle, U.S.G.S. 7.5 minute series. Lombard Limestone section measured along north-northwest to south-southeast traverse on hillside on the east side of the road along the west fork of Blacktail Deer Creek, beginning approximately 2.7 miles south of the confluence with Moonshine Gulch. The lower 1,032 feet of the Lombard, characterized by black, non-fossiliferous to fossiliferous mudstone, is probably fault thickened. Two southwest-northeast-trending stream valleys dissect the lower part of the Lombard and parallel the major north-down normal fault approximately 1.2 miles to the northwest, which juxtaposes Tertiary and Lower Mississippian units. Bedding attitudes of the few poorly exposed Lombard Limestone beds in the sections between these two valleys and the Mission Canyon Limestone are at high angles to the southwest-northeast trend of the Paleozoic units in this area; up to 80° of sinistral rotation is suggested by the northwest-southeast strike of these poorly exposed beds. The strike of the beds in the upper 991 feet of the Lombard parallels the strike of surrounding Paleozoic units in this area.

The Lombard Limestone is poorly to moderately well exposed at this location, on the southeast limb of a large, northeast-trending anticline. Talus obscures many parts of this section, however exposures on the north side and the upper part of the west side of the hill are adequate for measurement. Many thick beds crop out in this section, but most of them are less than 1.5 feet thick. The Kibbey Sandstone is missing here. The fault-thickened lower part of the Lombard, which is juxtaposed against the brecciated limestones of the upper part of the Mission Canyon Limestone, and the presence of the Kibbey at the Sawtooth Mountain area, only 4.4 miles to the northeast, both suggest that the Kibbey has been locally faulted out. The amount of fault thickening in the lower part of the Lombard is uncertain, but a minimum of 880 feet of extra section may be present, based on a comparison with the relatively complete, 1,143 foot thick section at Sawtooth Mountain. Zeigler (1954) measured 1,783 feet of Lombard Limestone here, but Perry (1983) has calculated a tectonically enhanced thickness of 2,350 feet. The amount of missing section in the uppermost Mission Canyon Limestone here also isunknown. Corals in the uppermost exposed Mission Canyon beds are of early Meramecian age (Coral Zone IIIA), suggesting that a minimum amount of section is missing; some of the thinning may be attributed to subaerial erosion related to regression of the Madison sea in Meramecian time, although faulting associated with the development of the Snowcrest Range must also be considered.

No corals were found in this section, however brachiopods are common and are often well preserved. Two species of brachiopods were retrieved from the float at the base of the hill; one identical and two different species were found in the described beds and/or float at discrete stratigraphic levels. The two species found at the base of the hill are Composita cf. C. subquadrata (Hall) and Anthracospirifer curvilateralis (Easton). The three species found in the upper part of the Lombard are Anthracospirifer curvilateralis (Easton), Antiquatonia sp., and Composita sp. The occurrence of these brachiopods, common to the late Paleozoic, and the stratigraphic position of these dark, fossiliferous and non-fossiliferous limestones between lithologies characteristic of the Mission Canyon Limestone and Amsden Formation support the assignment of these rocks to the Lombard Limestone.

This location can be approached from either the north or south, although the approach from the north is the shortest and easiest route to drive. To approach from the north, drive approximately 37 miles south from Dillon along the Blacktail Deer Creek road. From the south, drive east from Lima to Lima Reservoir dam. Continue approximately 8.7 miles east, staying north of the reservoir, until the road turn abruptly north. Follow the road north to the T-junction with Blacktail Deer Creek Road. Turn northwest and continue approximately 7.3 miles to the hillside exposure.

Unit	Lithology	Ft.
63	COVER: Very pale orange (10 YR 8/2) to pale grayish orange (10 YR 8/4) soil; scattered sandstone float, grayish orange (10 YR 7/4) to moderate reddish brown (10 R 4/6); basal Amsden Formation; small, massive sandstone outcrop 10' above inferred Lombard-Amsden contact	unm.
62	COVER: Medium brownish gray (5 YR 5/1) soil; abundant fossiliferous packstone and wackestone float, containing echinoid ossicles, disarticulated brachiopods, ostracodes, bryozoan fragments, high-spired gastropods; also non-fossiliferous mudstone float; several large wackestone/packstone float blocks (up to 5' diameter); relatively abrupt change in soil color at top (=inferred contact); uppermost Lombard Limestone	185
61	FOSSILIFEROUS PACKSTONE: Dark olive gray (5 Y 3/1), weathers to very light gray (N7); microcrystalline; thick beds with minor, discontinuous, parallel, slightly undulatory to undulatory, slabby splitting habit, alternating with thin to medium beds with non-parallel to parallel, undulatory, flaggy splitting habit; sharp, slightly undulatory to undulatory contacts between beds; vertical fractures ubiquitous in thick beds; echinoid ossicles, indeterminate ramose bryozoan fragments, disarticulated and broken brachiopods, tightly coiled gastropods; fossils randomly oriented and distributed; burrows(?); moderate petroliferous odor; ledge-former; well-exposed	9
60	COVER: Non-fossiliferous mudstone float, fossiliferous wackestone and packstone float	7
59	FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium to thick beds with minor parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel to non-parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds;	

echinoid ossicles, disarticulated and broken brachiopods, fenestrate and indeterminate bryozoan fragments, ostracodes; fossils randomly oriented and distributed; moderate petroliferous odor; subdued ledge-former; poorly to moderately well exposed..................14

58 COVER: Fossiliferous wackestone and mudstone float..8

57 BRACHIOPOD WACKESTONE/PACKSTONE: Olive gray (5 Y 4/1), weathers to medium gray (N5); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel to non-parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; many disarticulated and few whole brachiopods (including Composita sp.), echinoid ossicles, Cochliodont fish teeth, ostracodes; many fossils subparallel to bedding (weak shape fabric), randomly distributed; fossils more concentrated in few thin intervals (=packstones) within wackestone beds; weak petroliferous odor; subdued ledge-former; moderately well exposed; sharp, planar to slightly undulatory contact with unit 56.....................6

56 FOSSILIFEROUS WACKESTONE: Brownish black (5 YR 2/1), weathers to medium light gray (N6); microcrystalline; medium beds with parallel, slightly undulatory, flaggy splitting habit, alternating with thin beds with parallel, undulatory, laminated splitting habit; sharp, slightly undulatory to undulatory contacts between beds; whole and disarticulated brachiopods (chiefly Productids and Spiriferids), echinoid ossicles, indeterminate bryozoan(?) fragments; ostracodes; fossils randomly oriented and distributed; strong petroliferous odor; ledge-former....................4

55 COVER: Fossiliferous wackestone float, fossils in float include Antiquatonia sp. and Anthracospirifer curvilateralis Easton...........6

54 FOSSILIFEROUS WACKESTONE: Brownish black (5 YR 2/1), weathers to medium light gray (N6); microcrystalline; medium beds with

minor parallel, slightly undulatory, flaggy splitting habit, alternating with thin to medium beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory to undulatory contacts between beds; many disarticulated and few whole brachiopods (also few broken), indeterminate bryozoan fragments, ostracodes, gastropods; fossils subparallel to bedding to randomly oriented, randomly distributed; few whole brachiopods with geopetal fill; moderate to strong petroliferous odor; many thin, intermittent covered intervals; scattered ledge outcrops.........12

53 COVER: Fossiliferous wackestone and mudstone float; indeterminate trilobite mold in float..6

52 FOSSILIFEROUS WACKESTONE: Brownish black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium beds with very minor parallel, slightly undulatory, flaggy splitting habit, alternating with thin to predominantly medium beds with parallel to non-parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; echinoid ossicles, few whole and many disarticulated brachiopods, ostracodes(?); fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued ledge-former.................................9

51 COVER: Fossiliferous wackestone and mudstone float..4

50 FOSSILIFEROUS WACKESTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; medium beds (thinner than unit 52 beds) with ubiquitous vertical fractures and very minor, parallel, slightly undulatory, flaggy splitting habit, alternating with medium beds with parallel to non-parallel, undulatory, fissile to laminated splitting habit; echinoid ossicles, disarticulated brachiopods, gastropods; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former..........................3

49 COVER: Fossiliferous wackestone and mudstone float..3

48 FOSSILIFEROUS PACKSTONE: Olive gray (5 Y 4/1), weathers to light gray (N6); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with medium beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; few small, irregular to ovoid, olive black (5 Y 2/1) mud lenses; echinoid ossicles, whole and disarticulated brachiopods, disarticulated pelecypods and trilobites, indeterminate bryozoan fragments, ostracodes; fossils subparallel to bedding, randomly distributed, stand with slight relief on weathered surface; weak petroliferous odor; ledge-former................4

47 COVER: Fossiliferous packstone and wackestone float, minor fossiliferous mudstone float............6

46 FOSSILIFEROUS PACKSTONE: Medium olive gray (5 Y 5/1), weathers to medium gray (N5); microcrystalline; medium to thick beds (few thin beds) with parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with medium (few thick) beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory to undulatory contacts between beds; many disarticulated and few whole pelecypods, disarticulated brachiopods, abundant broken valves, echinoid ossicles, few bryozoan fragments, few disarticulated trilobites, ostracodes; fossils well packed, randomly oriented and distributed, stand with slight to moderate relief on weathered surface; weak petroliferous odor; subdued ledge-former, moderately well exposed, few thin covered intervals.............................15

45 COVER: Fossiliferous wackestone and packstone float, minor mudstone float.........................9

44 FOSSILIFEROUS WACKESTONE/PACKSTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium beds with parallel, slightly undulatory to undulatory, flaggy splitting habit, alternating with medium beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory contacts between beds;

echinoid ossicles and fragments, disarticulated and few broken brachiopods, disarticulated and few whole pelecypods, fenestrate bryozoan fragments, ostracodes; fossils randomly oriented and distributed; slight lateral variations in fossil density (=local packstones); scarce, very small pyrite masses; moderate petroliferous odor; subdued ledge-former............................4

43 COVER: Fossiliferous wackestone and mudstone float...8

42 FOSSILIFEROUS WACKESTONE/PACKSTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium to thick beds with absent to common, parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with medium to thick beds with parallel to locally non-parallel, undulatory, fissile to predominantly laminated splitting habit; sharp, slightly undulatory contacts between beds; disarticulated and broken brachiopods, echinoid ossicles, disarticulated pelecypods, ostracodes, indeterminate bryozoan fragments; fossils randomly oriented and distributed, locally subparallel to bedding, locally concentrated/densely packed (=packstones); swirled texture common (=bioturbation); moderate petroliferous odor; subdued ledge-former to local ledge-former; poorly exposed...............21

41 COVER: Fossiliferous wackestone and mudstone float...11

40 FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium to thick beds with minor parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with medium beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory to undulatory contacts between beds; echinoid ossicles, disarticulated brachiopods and pelecypods; fossils randomly oriented and distributed; local swirled texture (=bioturbation); moderate petroliferous odor; subdued ledge-former........9

39 COVER: Fossiliferous wackestone and mudstone float, minor non-fossiliferous mudstone float....................................10

38 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; medium to thick beds with minor parallel, slightly undulatory, slabby splitting habit, alternating with thick beds with parallel, slightly undulatory, fissile to predominantly laminated splitting habit; sharp, slightly undulatory contacts between beds; thin, planar to slightly undulatory lamina, locally grade upward into slightly swirled texture; lamina absent locally; few echinoid ossicles, ostracodes, disarticulted brachiopods, finely comminuted fossil debris; fossils parallel to bedding, randomly distributed; few randomly oriented burrows; moderate petroliferous odor; subdued ledge-former; laminated beds poorly exposed......................14

37 COVER: Mudstone and fossiliferous mudstone float...6

36 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; medium to thick beds with minor parallel, slightly undulatory, slabby splitting habit alternating with medium to thick beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory contacts between beds; thin, planar to slightly undulatory lamina, pass vertically into non-laminated intervals; few echinoid ossicles, disarticulated brachiopods and pelecypods(?), finely comminuted fossil debris; fossils subparallel to bedding, randomly distributed; few augen-shaped chert nodules (up to 3" high, 7" long); moderate petroliferous odor; subdued ledge-former.....................................13

35 COVER: Fossiliferous and non-fossiliferous mudstone float.....................................6

34 FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium beds with minor

parallel, slightly undulatory, flaggy splitting habit, alternating with thick beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory contacts between beds; thin, planar to locally slightly undulatory lamina; few echinoid ossicles, disarticulated brachiopods and pelecypods, ostracodes(?); fossils subparallel to bedding, randomly distributed; few small burrows; few small chert nodules; moderate petroliferous odor; subdued ledge-former.............4

33 COVER: Fossiliferous and non-fossiliferous mudstone float......................................5

32 FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with medium to thick beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory to locally planar contacts between beds; faint, planar lamina visible on weathered surface; disarticulated and broken brachiopods and pelecypods, echinoid ossicles and fragments; fossils subparallel to bedding, randomly distributed but locally concentrated in thin layers; moderate petroliferous odor; subdued ledge-former to local ledge-former.................................17

31 COVER: Fossiliferous wackestone and mudstone float..8

30 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium beds with minor parallel, slightly undulatory, flaggy splitting habit, alternating with medium to thick beds with parallel, slightly undulatory, fissile to laminated splitting habit; thin, planar to slightly undulatory lamina locally visible on weathered surface; few echinoid fragments, disarticulated brachiopods; fossils subparallel to bedding, randomly distributed; moderate to strong petroliferous odor; very subdued ledge-former; poorly exposed........................7

29 COVER: Fossiliferous wackestone and mudstone float, non-fossiliferous mudstone float............23

28 FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; thick beds with parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with medium to thick beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and few broken brachiopods and pelecypods, disarticulated trilobites, ostracodes, few fish teeth(?); fossils subparallel to bedding, randomly distributed, some slightly more concentrated in thin layers; moderate petroliferous odor; subdued ledge-former...........12

27 COVER: Fossiliferous wackestone and mudstone float...9

26 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium to thick beds with parallel, slightly undulatory to locally undulatory, flaggy to slabby splitting habit, alternating with medium to thick beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; faint, planar to slightly undulatory lamina locally visible on weathered surface; echinoid ossicles, disarticulated and broken brachiopods, few pelecypods, few disarticulated trilobites, few broken gastropods(?); fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; ledge-former...................7

25 COVER: Fossiliferous wackestone and mudstone float...11

24 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; medium and thick beds with minor discontinuous, parallel, slightly undulatory, flaggy to slabby splitting habit; sharp, slightly undulatory contacts between beds; faint,

planar to slightly undulatory lamina locally visible on weathered surface; echinoid ossicles and fragments, disarticulated and broken brachiopods, few broken pelecypods(?); fossils subparallel to locally parallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former............3

23 COVER: Fossiliferous wackestone and mudstone float, non-fossiliferous mudstone float.............4

22 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; medium beds with minor to locally significant, parallel, planar to slightly undulatory, flaggy splitting habit, alternating with medium to predominantly thick beds with parallel, slightly undulatory to undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory to locally planar contacts between beds; thin, slightly undulatory lamina locally visible on weathered surface; echinoid ossicles and fragments, disarticulated and few broken pelecypods and brachipods, ostracodes; most fossils subparallel to bedding, randomly distributed; few short, randomly oriented burrows; moderate petroliferous odor; subdued ledge-former...........12

21 COVER: Fossiliferous and non-fossiliferous mudstone float; minor fossiliferous wackestone float.................................16

20 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium and thick beds with minor discontinuous, parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with medium to thick beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory to undulatory contacts between beds; echinoid ossicles, many disarticulated and very few whole brachiopods and pelecypods, ostracodes; most fossils subparallel to bedding, randomly distributed; local, vertical variations in fossil density (=alternating very thin and thin fossiliferous mudstone and wackestone layers); few burrows(?); strong

petroliferous odor; subdued ledge-former.............9

19 COVER: Fossiliferous wackestone and mudstone float, non-fossiliferous mudstone float.............24

18 FOSSILIFEROUS WACKESTONE/MUDSTONE: Dark olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; medium beds with very minor, discontinuous, parallel, slightly undulatory, flaggy splitting habit, alternating with medium to thick beds with parallel, undulatory, fissile to laminated splitting habit; sharp, slightly undulatory to undulatory contacts between beds; echinoid ossicles and fragments, disarticulated brachiopods and pelecypods, ostracodes, gastropods; fossils randomly oriented and distributed; few mudstone beds, predominantly wackestone beds; moderate to strong petroliferous odor; subdued ledge-former to local ledge-former (wackestones); laminated intervals moderately well to predominantly poorly exposed..................................13

17 COVER: Fossiliferous wackestone and mudstone float, non-fossiliferous mudstone float..............8

16 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium to thick beds with parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with thick beds with parallel, slightly undulatory to undulatory, fissile to predominantly laminated splitting habit; sharp, slightly undulatory to locally undulatory contacts between beds; echinoid ossicles, whole and disarticulated pelecypods and (few) brachiopods, high-spired gastropods, ostracodes; fossils randomly oriented and distributed, fossils less concentrated locally (=thin mudstone intervals); moderate petroliferous odor; ledge-former.................................5

15 COVER: Fossiliferous and non-fossiliferous mudstone float; minor fossiliferous wackestone float.................................11

14 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; medium beds with discontinuous, parallel, slightly

undulatory, flaggy splitting habit, alternating with medium to thick beds with parallel, slightly undulatory to undulatory, fissile to predominantly laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated pelecypods and brachiopods, ostracodes; fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former; separated from unit 13 by medium/laminated bed, with sharp, slightly undulatory contact..4

13 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium beds with parallel, slightly undulatory, flaggy splitting habit, alternating with medium to thick beds with parallel, undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory to locally planar contacts between beds; echinoid ossicles and fragments, ostracodes, few gastropods, few disarticulated pelecypods(?); fossils randomly oriented and distributed; horizontal burrows; strong petroliferous odor; subdued ledge-former..........................7

12 COVER: Fossiliferous and non-fossiliferous mudstone float....................................3

11 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; thick bed with minor, discontinuous, parallel, slightly undulatory, flaggy splitting habit, between two very poorly exposed beds with parallel, undulatory, laminated splitting habit; echinoid ossicles and fragments, disarticulated and broken pelecypods and brachiopods, high-spired gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former.....................................2

10 COVER: Fossiliferous and non-fossiliferous mudstone float....................................4

9 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to very pale orange (10 YR 8/2) to light gray (N7); microcrystalline; thick beds with minor

discontinuous, parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thick beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, few gastropods, few disarticulated pelecypods; fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former............6

8 COVER: Fossiliferous and non-fossiliferous mudstone float.......................................3

7 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; thick bed with parallel, planar to slightly undulatory, flaggy to slabby splitting habit, between two poorly exposed beds with parallel, slightly undulatory to undulatory, laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, disarticulated pelecypods, ostracodes, few gastropods; fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former.......................................2

6 COVER: Vegetated; scattered fossiliferous and non-fossiliferous mudstone float; dark brownish gray soil................................295

5 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; thick(?) beds with parallel, planar to slightly undulatory, fissile to predominantly laminated splitting habit; echinoid ossicles, whole and disarticulated pelecypods, ostracodes, few gastropods; fossils parallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former............3

4 COVER: Grassy; dark brownish gray soil; fossiliferous and non-fossiliferous mudstone float.......................................4

3 FOSSILIFEROUS MUDSTONE/WACKESTONE: Olive black (5 Y 2/1) to black (N1), weathers to light gray (N7) to very pale orange (10 YR 8/2); microcrystalline; medium to predominantly thick beds with absent to

minor, parallel, planar to slightly undulatory, slabby to blocky splitting habit, alternating with thick to very thick beds wtih parallel, planar to slightly undulatory, fissile to laminated splitting habit; variable contacts between beds: some sharp and planar to slightly undulatory, most gradational contacts; many slabby/blocky beds grade laterally into fissile/laminated beds; faint, very thin to thin, planar lamina locally visible on weathered surface; whole and disarticulated pelecypods (few with geopetal fill), few disarticulated brachiopods, ostracodes, echinoid ossicles and few partial stems, gastropods; most fossils parallel to bedding, many concentrated in discrete layers, others randomly distributed; fossils locally in pod-shaped clusters; indeterminate (grazing(?), feeding(?)) trace fossils on many bedding planes; few beds with local, denser concentration of fossils (=wackestones); strong petroliferous odor; ledge-former.................... 38

2 COVER: Brownish black (5 YR 2/1) soil; scattered fossiliferous and non-fossiliferous mudstone float; rare, small, scattered outcrops of fossiliferous to predominantly non-fossiliferous mudstone; weakly discernable bedding striking at high angles to beds of units 3-63.................... 1,032

1 BRECCIATED WACKESTONE: Dark olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; thick to very thick beds, crudely bedded, massive to locally blocky splitting habit; many disarticulated and few whole pelecypods and brachiopods (many Spiriferids), echinoid ossicles, corals (including Vesiculophyllum sp. and Diphyphyllum sp.), few ostracodes; fossils randomly oriented and distributed, local weak shape fabric, stand with slight relief on weathered surface; moderate to strong petroliferous odor; locally brecciated, underlain by limestone solution breccias and paleokarst.................. unm.

TOTAL: 2,023.0 feet

III. SAWTOOTH MOUNTAIN SECTION

Sections 8 and 9, T. 12 S., R. 5 W., Antone Peak quadrangle, U.S.G.S. 7.5 minute series. Kibbey Sandstone and Lombard Limestone section measured at two locations: units 1-5 measured on north-facing cliffs just west of the head of Indian Creek (NW 1/4, SE 1/4, NE 1/4, section 9); units 6-60 measured at prominent hill (summit elevation 9,566') just west-northwest of the western end of Sawtooth Mountain, in section 8. Units 6-12 measured on dip slope on the south-southeast side of the hill in section 8 (NW 1/4, SE 1/4, and at SW 1/4, NE 1/4, section 8). Units 13-60 measured on the west-northwest side of the hill, at W 1/2, SW 1/4, and at SE 1/4, NE 1/4, NW 1/4, section 8.

The Kibbey Sandstone is very poorly exposed in this area, but one 12-foot thick ledge sequence crops out at the edge of the talus apron at the base of the west side of the hill in section 8. Unit 18 (Lombard Limestone) is best exposed as cliffs just north-northeast of the summit of the hill in section 8. Unit 6 (Lombard Limestone) is exposed in a large gully at the base of the dip slope of the previously mentioned hill. Several feet of unit 6 shales also crop out at the base of the north-facing cliffs (section 9), but the relationship of these shales with those in the gully, with respect to the true stratigraphic thickness of this unit, is uncertain. Based on this uncertainty, and because the shale sequence exposed in the gully is the thickest of the two exposures, the value obtained in the gully is used in this report; this thickness value is considered a minimum value.

This area can be approached from the south or from the northeast. To approach from the south, drive up Antone Peak Road (FR 325) to Cornell Camp (NE 1/4, section 20). Hike north along Cornell trail to Sawtooth trail, turning northeast at this junction and proceeding along the latter trail to the west end of Sawtooth Mountain. To approach from the northeast, drive east-southeast on the East Fork Blacktail Deer Creek Road until it ends at Indian Creek (section 34, T. 11 S., R. 5 W.). Hike across Indian Creek and then continue south-southwest along Sawtooth trail, paralleling the creek most of the way to the north face of Sawtooth Mountain. Both access roads branch off of Blacktail Deer Creek Road, so approaches from both Lima and Dillon are possible. These roads traverse several exposures of Tertiary clays and, as a result, are very slippery and unsafe to travel during and immediately after heavy rains.

Unit	Lithology	Ft.
60	QUARTZ ARENITE: Pale yellowish brown (10 YR 6/2), weathers to moderate brown (5 YR 4/4) to very pale orange (10 YR 8/2); fine to medium grained; calcite-cemented; small, subangular to subrounded limestone clasts along base of unit; crudely normal graded; ledge-former................	unm.
59	MUDSTONE: Color mottled; moderate brown (5 YR 3/4) and very light olive gray (5 Y 7/1), weathers to moderate brown (5 YR 4/4) and medium light gray (N6), respectively; few small, oval to round, very light gray (N8) mottles; microcrystalline; medium, planar to undulatory bed with minor parallel, undulatory, flaggy splitting habit; vertical fractures ubiquitous; sharp, undulatory (2" relief), erosional contact with unit 60; sharp, slightly undulatory contact with unit 58; moderate petroliferous odor; subdued ledge-former.......................................	1
58	MUDSTONE: Dark yellowish brown (10 YR 4/2), weathers to light olive gray (5 Y 6/1) to light gray (N7); microcrystalline; parallel, to non-parallel, undulatory, thin beds with calcareous shale partings; non-fossilifeous; non-rhythmic ripples(?) with 1/2" relief; bioturbated; few burrows(?); very small chert nodules; moderate petroliferous odor; subdued ledge former................................	6
57	MUDSTONE: Faintly color mottled; olive gray (5 Y 4/1) and light olive gray (5 Y 6/1), weathers overall to pale grayish orange (10 YR 8/4) to pale brown (5 YR 5/2); microcrystalline; planar, thick beds with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with medium to predominantly thin, planar beds with parallel, planar to undulatory, fissile to laminated splitting habit; bioturbated(?); non-fossiliferous; minor dolomite associated with mottles; pyrite common in darker mottles; color gradually changes upsection to dark yellowish brown (10 YR 7/2) and dark yellowish orange (10 YR 6/2) mottles, weather to pale yellowish brown (10 YR 6/2) and pale	

yellowish orange (10 YR 8/6), respectively; pyrite absent in upper part of unit; weak petroliferous odor; subdued ledge-former; gradational contacts with units 58 and 56...........41

56 DOLOMITIC MUDSTONE: Color mottled: brownish gray (5 YR 4/1) and medium olive gray (5 Y 5/1), weathers to olive gray (5 Y 4/1) and yellowish gray (5 Y 7/2), respectively; microcrystalline; planar, medium to thick beds with parallel, planar to very slightly undulatory, laminated to flaggy splitting habit; non-fossiliferous; bioturbated(?); burrows(?); disseminated pyrite; weak petroliferous odor; ledge-former; gradational contact with underlying shales (unit 55)..................................19

[NOTE: section description traverse offset 0.9 miles to large gully with excellent shale outcrops; NW 1/4, SE 1/4, section 8]

55 CALCAREOUS SHALE: Black (N1), weathers to yellowish gray (5 Y 8/1); silty; microcrystalline; thin, planar beds with parallel, planar to very slightly undulatory, laminated to predominantly fissile splitting habit; very thin, planar lamina visible on weathered surface; minor pyrite; very strong petroliferous odor; well exposed; slope-former...................42

54 COVER: Grassy dip slope; fossiliferous wackestone and packstone float; minor limestone conglomerate float........................8

53 LIMESTONE CONGLOMERATE: Pebbles and cobbles, Black (N1) to moderate olive gray (5 Y 4/2) to dark brownish gray (5 YR 3/1), set in pale yellowish orange (10 YR 8/6) to grayish orange (10 YR 7/4) matrix; weathers overall to medium gray (N5) to yellowish gray (5 Y 7/2); no discernable bedding; parallel, undulatory, flaggy to slabby splitting habit; clasts of non-fossiliferous mudstone, sparsely fossiliferous and fossiliferous wackestone, phosphatic pellets; many clasts with internal iron stain as several discrete bands parallel to clast margins; matrix of "floating" fossils (disarticulated and broken brachiopods and pelecypods, bryozoan and trilobite debris, echinoid ossicles),

limestone granules, micrite, sparry calcite, and quartzose silt; poorly sorted; clasts subangular to predominantly rounded, equidimensional to elongate; no shape fabric; lensoidal(?) deposit (local occurrence, thins laterally, absent elsewhere on dip slope); moderately well exposed; very subdued ledge-former..................3

52 COVER: Grassy dip slope; fossiliferous wackestone and packstone float (similar to float of unit 50)...............................10.5

51 FOSSILIFEROUS PACKSTONE: Medium gray (N5), weathers to grayish orange (10 YR 7/4); microcrystalline; no discernable bedding; parallel, planar to slightly undulatory, flaggy to slabby splitting habit; fenestrate bryozoan debris, whole and disarticulated brachiopods (few broken), echinoid ossicles, few gastropods; most fossils parallel to bedding, randomly distributed, stand with slight relief on weathered surface; weak petroliferous odor; very subdued ledge-former; poorly exposed...........1.5

50 COVER: Grassy dip slope; fossiliferous wackestone and packstone float; wackestone contains abundant bryozoan fragments, echinoid ossicles, whole and disarticulated brachiopods, ostracodes; packstone float similar to unit 51; also scattered, whole to slightly broken, large cup corals (including _Siphonophyllia_ sp., _Michelinia_ cf. _M. meekana_ Girty) and brachiopods (including _Antiquatonia_ aff. _A. pernodosa_ Easton, _Inflatia_ aff. _I. richardsi_ Girty, _Anthracospirifer curvilateralis_ Easton).............21

49 FOSSILIFEROUS GRAINSTONE: Brownish gray (5 YR 4/1), weathers to medium olive gray (5 Y 5/1); microcrystalline; no discernable bedding; parallel, slightly undulatory, blocky splitting habit; echinoid ossicles, disarticulated and broken brachiopods, fenestrate and indeterminate ramose bryozoan fragments, few whole pelecypods, gastropods, ostracodes; most fossils parallel to bedding, randomly distributed, stand with moderate relief on weathered surface; weak petroliferous odor; very subdued ledge-former, poorly exposed................2

48 COVER: Grassy; scattered grainstone float.............4

47 FOSSILIFEROUS GRAINSTONE: Brownish gray (5 YR 4/1), weathers to medium olive gray (5 Y 5/1); microcrystalline; no discernable bedding; parallel, slightly undulatory, flaggy splitting habit; echinoid ossicles and fragments; fenestrate and indeterminate ramose bryozoan fragments, disarticulated and broken brachiopods, ostracodes, gastropods; most fossils parallel to bedding, randomly distributed; weak petroliferous odor; very subdued ledge-former..1

46 COVER: Grassy; minor fossiliferous packstone and grainstone float.................................7

45 FOSSILIFEROUS PACKSTONE: Medium brownish gray (5 YR 5/1), weathers to medium olive gray (5 Y 5/1); moderately saccharoidal (recrystallized); medium(?) beds with parallel, slightly undualtory, slabby splitting habit; echinoid ossicles, bryozoan fragments (fenestellid, trepostome, and rhabdomesid varieties), whole and disarticulated brachiopods (including _Composita_ sp.) and pelecypods, corals (including _Amplexizaphrentis_ sp.), gastropods, trilobites, indeterminate orthoconic nautiloid debris; fossils randomly oriented and distributed, stand with slight relief on weathered surface; few, small sylolites; slickensides on fracture surfaces; very weak petroliferous odor; subdued ledge-former; poorly exposed...........3

44 COVER: Grassy; fossiliferous wackestone and packstone float....................................12

43 FOSSILIFEROUS PACKSTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); moderately crystalline (recrystallized); thick to very thick, planar beds with minor parallel, planar to slightly undulatory, blocky to massive splitting habit, alternating with medium to predominantly thin, planar to undulatory limy shale beds; sharp contacts between beds; whole and disarticulated brachiopods, large cup corals (including _Siphonophyllia_ sp.), gastropods, echinoid ossicles, ostracodes, few disarticulated and broken pelecypods; fossils randomly oriented and distributed; few randomly oriented

burrows; weak to moderate petroliferous odor; ledge-former...............................15

42 COVER: Grassy; fossiliferous wackestone float..........5

41 BRYOZOAN WACKESTONE/PACKSTONE: Brownish gray (5 YR 4/1), weathers to light gray (N7) to grayish orange (10 YR 7/4); microcrystalline; thick, planar wackestone beds with parallel to non-parallel, undulatory, flaggy splitting habit, alternating with medium, planar beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; fissile intervals pass laterally into laminated intervals; two thin, slightly undulatory packstone interbeds with parallel, undulatory, laminated splitting habit occur near top of wackestone beds; fenestrate, rhabdomesid, and trepostome bryozoans (many long, ramose and dendroid fragments), disarticulated brachiopods, echinoid ossicles, gastropods; most fossils parallel to bedding, randomly distributed; packstone interbeds predominantly bryozoans, and pinch out laterally over a few tens of feet; subdued ledge-former; moderately well exposed...6

40 COVER: Grassy; scarce fossiliferous wackestone float..................................4

39 BRYOZOAN WACKESTONE: Brownish gray (5 YR 4/1), weathers to very light gray (N8) to pale orange (10 YR 8/2); microcrystalline; thick to predominantly medium, planar beds with parallel to locally non-parallel, undulatory, flaggy splitting habit, alternating with thin to medium, planar beds with parallel, planar to undulatory, fissile to predominantly laminated splitting habit; fissile intervals pass laterally into laminated intervals; fenestrate, rhabdomesid, and trepostome bryozoan fragments (many long, ramose and dendroid fragments), disarticulated brachiopods (including Composita sp., many indeterminate Spiriferids and Productids), echinoid ossicles, tightly coiled gastropods, ostracodes; most fossils parallel to bedding, few at high angles, randomly distributed, stand with moderate relief on weathered surface; few chert

pods and stringers (up to 18" long), primarily in thin to medium, laminated beds; moderate petroliferous odor; subdued ledge-former; laminated and fissile intervals typically poorly to moderately well exposed....................................19

38 COVER: Grassy; fossiliferous wackestone float...5

37 FOSSILIFEROUS PACKSTONE: Dusky yellowish brown (10 YR 2/2), weathers to pinkish gray (5 YR 8/1); microcrystalline; thick(?) beds with parallel, planar to slightly undulatory, laminated to flaggy splitting habit; whole and disarticulated brachiopods, echinoid ossicles, ramose bryozoan debris; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; very subtle ledge-former; poorly exposed.........................4

36 COVER: Grassy; fossiliferous wackestone and packstone float....................................9

35 BRACHIOPOD PACKSTONE: Medium dark gray (N4), weathers to pinkish gray (5 YR 8/1); microcrystalline; thick beds with parallel, planar to slightly undulatory, flaggy to laminated splitting habit, alternating with thin to very thin limy shale beds (slightly silty); disarticulated and few broken brachiopods, echinoid ossicles, ramose bryozoans; most fossils parallel to bedding, randomly distributed; few, local intervals slightly less fossiliferous (=wackestones); subdued ledge-former; poorly exposed (small, scattered exposures with many thin, intermittent covered intervals)....................27

34 COVER: Grassy; fossiliferous wackestone and packstone float...................................17

33 BRACHIOPOD WACKESTONE/PACKSTONE: Medium dark gray (N4), weathers to brownish gray (5 YR 4/1); microcrystalline; thick, planar beds with parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with thin limy shale beds (slightly silty); predominantly disarticulated and few broken brachiopods, echinoid ossicles, cryptostome(?) bryozoan fragments, ostracodes; most fossils parallel to bedding, randomly distributed;

brachiopods most abundant (=packstones) in flaggy intervals; local, small mud injection structures from limy shale interbeds; moderate petroliferous odor; subdued ledge-former; moderately well exposed, few thin covered intervals................36

32 COVER: Mudstone and fossiliferous wackestone float...13

31 FOSSILIFEROUS WACKESTONE/PACKSTONE: Dark gray (N3), weathers to light olive gray (5 Y 6/1); microcrystalline; medium to predominantly thick beds with parallel, planar to slightly undulatory, laminated to flaggy splitting habit, alternating with medium to predominantly thin, slightly undulatory limy shale beds; whole and disarticulated brachiopods (including Anthracospirifer curvilateralis Easton), echinoid ossicles, gastropods, bryozoan and coral(?) fragments, ostracodes; fossils randomly oriented and distributed; lateral variations in fossil density create a variable wackestone to packstone lithology locally, but wackestones most common; crops out as small, scattered ledges with many thin, intermittent covered intervals...............................42

30 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to light olive gray (5 Y 6/1); microcrystalline; thick, planar to slightly undulatory beds with parallel, planar to slightly undulatory, slabby to blocky splitting habit alternating with thick, slightly undulatory beds with parallel, planar to slightly undulatory, laminated splitting habit; slabby/blocky beds grade upward into slightly thicker flaggy beds, but sharp contact between flaggy and overlying slabby/blocky beds; very few echinoid ossicles, ostracodes; fossils subparallel to bedding, randomly distributed; few burrows(?); very strong petroliferous odor; very subdued ledge-former to slope-former; poorly exposed..................28

29 COVER: Mudstone float.............................8

28 ECHINOID PACKSTONE: Olive gray (5 Y 4/1), weathers to medium light gray (N6); microcrystalline; thick, planar beds with

parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin to medium, slightly undulatory, slightly silty, limy shale beds; many echinoid ossicles (including Pentacrinus) and partial stems, bryozoan fragments, disarticulated and broken brachiopods, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; very subdued ledge-former............................4

27 COVER: Mudstone and fossiliferous packstone float..4

26 ECHINOID PACKSTONE: Olive gray (5 Y 4/1), weathers to medium gray (N5); microcrystalline; thick, planar beds with parallel, planar to slightly undulatory, flaggy to rarely slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, fissile to laminated splitting habit; fissile intervals slightly siltier; many echinoid ossicles (including Pentacrinus) and partial stems, disarticulated and broken brachiopods, bryozoan fragments, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; subdued ledge-former...................................15

25 COVER: Silty limestone and fossiliferous wackestone float.....................................11

24 FOSSILIFEROUS WACKESTONE: Pale brown (5 YR 5/2), weathers to very light gray (N8); microcrystalline; thick to very thick, planar beds with parallel, planar to slightly undulatory, flaggy to less commonly slabby or blocky splitting habit, alternating with thin to medium beds with parallel, undulatory, discontinuous to continuous, fissile to laminated splitting habit; bryozoan fragments, echinoid ossicles, whole and disarticulated brachiopods, disarticulated pelecypods(?); fossils randomly oriented and distributed; moderate petroliferous odor; subdued ledge-former; laminated/fissile intervals typically poorly exposed to covered.................24

23 COVER: Silty shale and fossiliferous wackestone float.....................................6

22 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to medium light gray (N6); microcrystalline; medium to thick (rare very thick beds), planar beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin to medium beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; fissile intervals slightly silty; echinoid ossicles and partial stems, whole and disarticulated brachiopods (including Spirifer cf. S. brazerianus Girty), few small and broken corals(?), ostracodes; fossils randomly oriented and distributed; one 5" thick storm(?) layer of concentrated fossil debris (fossils parallel to bedding) approximately 3' above base of unit; few vertical to inclined burrows; few small chert stringers; moderate petroliferous odor; subdued ledge-former; laminated/fissile intervals variably exposed, typically poorly exposed....................21

21 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to light gray (N7); microcrystalline; thick, planar beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin beds with parallel, slightly undulatory, laminated to predominantly fissile splitting habit; thin, fissile beds display crude thickening upward trend; sharp, slightly undulatory to undulatory contacts between beds; very few brachiopod fragments; fossils subparallel to bedding, randomly distributed; very strong petroliferous odor; subdued ledge-former; sharp, undulatory contact with unit 22......................9

20 COVER: Mudstone and fossiliferous mudstone float...17

19 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to light gray (N7); microcrystalline; medium to thick, planar beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin beds of limy shale; few brachiopod fragments; fossils parallel to bedding, randomly distributed; very strong petroliferous odor; subdued ledge-former.......................................10

18 COVER: Mudstone float....................................4

17 MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; medium, planar beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin beds of limy shale; very thin, planar lamina locally visible on weathered surface; non-fossiliferous(?); very strong petroliferous odor; poorly exposed..6

16 COVER: Mudstone float....................................11

15 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; medium, planar beds with parallel, slightly undulatory, flaggy splitting habit, alternating with thin beds of limy shale; very thin, planar lamina visible on weathered surface; few brachiopod(?) fragments oblique to lamina, randomly distributed; very strong petroliferous odor; very subdued ledge-former...16

14 COVER: Mudstone and fossiliferous mudstone float...7

13 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to very light gray (N8); microcrystalline; slightly silty; bedding poorly exposed, but generally thin to medium with parallel, slightly undulatory, flaggy splitting habit, alternating with thin beds of limy shale; few echinoid ossicles, ostracodes(?); fossils randomly oriented and distributed, stand with slight relief on weathered surface; very strong petroliferous odor..........................9

12 COVER: Mudstone and fossiliferous mudstone float...12

11 FOSSILIFEROUS MUDSTONE: Black (N1), weathers to yellowish gray (5 Y 8/1); microcrystalline; thick, planar beds with minor parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; minor, slightly undulatory shaly partings between beds; sharp contacts between beds;

very thin, non-rhythmic, planar lamina commonly visible on weathered surface; "thick" beds thinner overall than those of unit 10; echinoid ossicles, small brachiopod fragments, disarticulated pelecypods, gastropods, ostracodes; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; oily coating on some fracture surfaces; subdued ledge-former; moderately well exposed...17

10 FOSSILIFEROUS MUDSTONE: Grayish black (N2), weathers to medium gray (N5); microcrystalline; thick to very thick, planar beds with parallel, planar to slightly undulatory, flaggy to slabby, locally laminated, splitting habit, alternating with thin to medium beds with parallel, planar to rarely slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds, planar contacts less common and typically at base of thin/medium beds; extensively fractured; echinoid ossicles and fragments, disarticulated pelecypods, few gastropods, ostracodes; most fossils parallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former; poorly to moderately well exposed, but characterized by many brief covered intervals....................................66

9 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 4/1), weathers to light gray (N7); microcrystalline; thick, planar beds with parallel, slightly undulatory, flaggy splitting habit, alternating with medium beds with parallel, planar to slightly undulatory, fissile to rarely laminated splitting habit; few echinoid ossicles and fragments, ostracodes, small brachiopod(?) fragments; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; very subdued ledge-former; poorly to moderately well exposed..........................20

8 FOSSILIFEROUS MUDSTONE: Grayish black (N2), weathers to yellowish gray (5 Y 8/1); microcrystalline; thick to predominantly medium, planar beds with parallel, planar to slighlty undulatory laminated to flaggy splitting habit, alternating with slightly silty, medium beds with parallel, planar to

slightly undulatory, laminated to predominantly fissile splitting habit; few disarticulated and broken pelecypods and small brachiopods(?), ostracodes; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former; poorly to moderately well exposed..42

7 FOSSILIFEROUS MUDSTONE: Grayish black (N2); weathers to medium light gray (N6); microcrystalline; thick, planar beds with parallel, planar slightly undulatory, flaggy splitting habit, alternating with medium beds with parallel, planar to undulatory, laminated to predominantly fissile splitting habit; very thin, planar lamina visible on weathered surface; sharp contacts between beds; few disarticulated pelecypods, ostracodes; fossils parallel to bedding, randomly distributed; small burrows(?); strong petroliferous odor; subdued ledge-former; poorly exposed...............13

6 MUDSTONE: Black (N1), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium to thick, planar beds with parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; rare shaly partings; sharp, planar to slightly undulatory contacts between beds; planar lamina locally visible on weathered surfaces; few very small, indeterminate fossil fragments; many small, augen-shaped chert nodules; strong petroliferous odor; subdued ledge-former; poorly to moderately well exposed......................................17

5 MUDSTONE: Dark gray (N3), weathers to very pale orange (10 YR 8/2); microcrystalline; parallel, planar medium beds with parallel, slightly undulatory, flaggy splitting habit, alternating with thin to medium beds with parallel, planar to undulatory, laminated to predominantly fissile splitting habit; sharp, planar to undulatory contacts between beds (where exposed); planar lamina visible on weathered surfaces of medium, flaggy beds; no fossils visible in outcrop; rare, small chert nodules; strong petroliferous odor; subdued ledge-former............32

4 COVER: Moderate brown (5 YR 4/4) to moderate yellowish brown (10 YR 5/4) soil with sandstone float, passes upsection into light gray (N7) to medium gray (N5) limestone talus field at base of northwest-facing cliff/slope; represents transition from Kibbey Sandstone into Lombard Limestone....................................34

3 QUARTZ ARENITE: Very pale orange (5 YR 8/2) to yellowish gray (5 YR 4/4), weathers to moderate brown (5 YR 4/4) to grayish orange (10 YR 7/4); fine to medium grained; medium, planar to slightly undulatory beds; parallel, undulatory lamina locally visible in upper part; lower part massive to mottled; iron-stained; subdued ledge-former; only outcrop of Kibbey Sandstone...................12

2 COVER: Gentle, grassy slope; small sandstone fragments common in upper 48 feet.................250

1 COVER/SPARSELY FOSSILIFEROUS MUDSTONE: Medium greenish gray (5 G 5/1), weathers to medium olive gray (5 Y 5/1); microcrystalline; crude, thick beds; thoroughly brecciated/fractured; few echinoid ossicles, brachiopod fragments, ostracodes; fossils randomly oriented and distributed; slightly recrystallized; very poorly exposed throughout grassy hillside as small outcrops with very little relief; probably Mission Canyon Limestone...................................unm.

TOTAL (MAXIMUM): 1,109.0 feet

(Base not exposed)

IV. SUNSET PEAK SECTION

NW 1/4, SE 1/4, section 24, T. 11 S., R. 5 W., Antone Peak quadrangle, U.S.G.S. 7.5 minute series. Partial Lombard Limestone section measured in the saddle and on the southeast side of the hill (summit elevation 9,903') just northwest of Sunset Peak. The section traverse begins in the saddle between the hill and Sunset Peak, at the inferred Lombard-Amsden contact. This inferred contact is placed at the base of the stratigraphically lowest exposed sandstone rib (believed to be correlative to the Tyler Sandstone).

Only the upper 391.5 feet of the Lombard Limestone are exposed here, as this interval has been thrust over by Mission Canyon Limestone, subsequent to or contemporaneous with folding and overturning. All of the Paleozoic and Mesozoic units are overturned in this area. The northeast side of the hill is characterized by high Mission Canyon and Lodgepole Limestone cliffs. The Lombard is largely obscured or buried under talus shed from these overlying cliffs. The Lombard is variably exposed on the east-southeast side of the hill; talus from the Mission Canyon obscures a few intervals. The topographic expression of the uppermost Lombard, similar to that seen at Sawtooth and Hogback Mountains, suggests a buried shale/mudstone lithology in this uppermost stratigraphic interval. Some bed-on-bed fault thinning or thickening, obscured by talus, may have occurred within the exposed Lombard sequence, although this could not be substantiated.

This area can be approached from the northeast or the west; the latter route is the shortest. To reach this location from the west, drive southeast from Blacktail Deer Creek road on FR 963 (along the east fork of Blacktail Deer Creek) to its end at Indian Creek. Hike southeast along the east fork of Blacktail Deer Creek to the confluence of Crows Nest Creek. Turn northeast and follow this creek to its origin just below the saddle by Sunset Peak. To approach the saddle from the northeast, drive to the "Notch" (see Hogback Mountain section), and hike southwest along Robb Creek until it turns east toward the saddle between Sunset and Olson Peaks. At this bend in the creek, continue south-southwest to the saddle northwest of Sunset Peak.

Unit	Lithology	Ft.
19	SANDSTONE: Basal Amsden Formation; subdued ledge-former..	unm.
18	COVER: Grassy; dark brownish gray (5 YR 3/1) soil; abundant fossiliferous wackestone, fossiliferous and non-fossiliferous mudstone float....................................	266
17	FOSSILIFEROUS WACKESTONE: Light olive gray (5 Y 6/1), weathers to light brown (5 YR 6/1); finely crystalline (recrystallized); dolomitic; slightly silty; medium (few thick) undulatory beds with parallel, slightly undulatory to predominantly undulatory, flaggy to slabby splitting habit; undulatory, carbonaceous shale partings between beds; echinoid ossicles, disarticulated and broken pelecypods and brachiopods; most fossils subparallel to locally parallel to bedding, randomly distributed; many small, black, carbonaceous fragments and flakes, subparallel to bedding; extensively fractured; black (N1) to brownish black (5 Y 2/1) film locally on fracture surfaces; weak to moderate petroliferous odor; ledge-former..................................	10.5
16	COVER: Grassy; fossiliferous wackestone and mudstone float....................................	26
15	FOSSILIFEROUS WACKESTONE/PACKSTONE: Brownish gray (5 YR 4/1), weathers to moderate yellowish brown (10 YR 5/4); finely crystalline (recrystallized); dolomitic; slightly silty to sandy; medium to thick beds with minor parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit; slightly undulatory to undulatory carbonaceous shale partings between beds; few whole and many small disarticulated and broken brachiopods, few disarticulated pelecypods, ostracodes; most fossils subparallel to bedding; randomly distributed, stand with slight relief on weathered surface; many small carbonaceous fragments, subparallel to bedding; few medium beds with greater fossil density (=packstones), anastomosing carbonaceous(?) filaments, very thin and thin undulatory lamina locally visible on weathered surface, abundant quartzose	

silt; moderate petroliferous odor; ledge-former..11

14 COVER: Fossiliferous wackestone and mudstone float; minor non-fossiliferous mudstone float..3

13 FOSSILIFEROUS WACKESTONE: Dark brownish gray (5 YR 3/1), weathers to moderate yellowish brown (10 YR 5/4); finely crystalline (recrystallized); dolomitic; slightly silty to sandy; medium beds with minor parallel, undulatory, flaggy splitting habit; slightly undulatory to undulatory, carbonaceous shale partings between beds; disarticulated and broken brachiopods and pelecypods(?), echinoid ossicles; fossils subparallel to bedding, randomly distributed; many small carbonaceous fragments, parallel to bedding; brownish black (5 Y 2/1) film locally on fracture surfaces; moderate to strong petroliferous odor; ledge-former..................................6

12 COVER: Fossiliferous wackestone and mudstone float; also non-fossiliferous mudstone float..12

11 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; medium beds with minor parallel, slightly undulatory, flaggy splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, fissile to predominantly laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, disarticulated pelecypods, ostracodes; most fossils parallel to bedding, randomly distributed; many short, horizontal burrows; moderate to strong petroliferous odor; subdued ledge-former............9

10 COVER: Fossiliferous and non-fossiliferous mudstone float......................................4

9 FOSSILIFEROUS MUDSTONE: Grayish black (N2), weathers to light gray (N7); microcrystalline; medium to predominantly thick beds with parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting

habit; sharp, planar to locally slightly undulatory contacts between beds; some flaggy/slabby intervals pass laterally into fissile/laminated intervals; few echinoid ossicles and fragments, disarticulated and broken pelecypods and brachiopods, ostracodes; most fossils subparallel to bedding, randomly distributed; few short, horizontal to randomly oriented burrows; strong petroliferous odor; subdued ledge-former....................................12

8 COVER: Fossiliferous and non-fossiliferous mudstone float.....................................4

7 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; medium to thick beds with parallel, planar to slightly undulatory, slabby to locally flaggy splitting habit, alternating with medium beds with parallel to locally non-parallel, slightly undulatory, laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, disarticulated pelecypods and brachiopods, few ostracodes; fossils randomly oriented and distributed; moderate petroliferous odor; very subdued ledge-former; poorly exposed.........................5

6 COVER: Fossiliferous and non-fossiliferous mudstone float.....................................3

5 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy to predominantly slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; few echinoid ossicles and fragments, disarticulated pelecypods and brachiopods(?), few broken gastropods(?); fossils parallel to bedding (except for ossicles which are randomly oriented), randomly distributed; few short, horizontal burrows; strong petroliferous odor; subdued ledge-former; fissile/laminated intervals poorly exposed....................................11

4 COVER: Fossiliferous and non-fossiliferous mudstone float....................................2.5

3 FOSSILIFEROUS MUDSTONE: Grayish black (N2), weathers to medium light gray (N6); microcrystalline; medium to thick beds with parallel, slightly undulatory to locally planar, slabby splitting habit, alternating with thin and few medium beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; lower part of unit extensively fractured; sparsely fossiliferous; few echinoid ossicles, disarticulated and broken pelecypods and brachiopods; most fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former.............7

2 THRUST FAULT: Crush zone; variably sized Lombard Limestone and Mission Canyon Limestone fragments; thick, anastomosing fractures filled with coarse, milky calcite.........(2)

1 DOLOMITIC LIMESTONE: Medium brownish gray (5 YR 5/1), weathers to medium gray (N5); recrystallized; extensively brecciated; very crude, very thick bedding; weak petroliferous odor; cliff-former; Thrust sliver of Mission Canyon Limestone.................unm.

TOTAL: 391.5 feet

V. HOGBACK MOUNTAIN SECTION

SW 1/4, NE 1/4, and SE 1/4, section 6, T. 11 S., R. 4 W., Swamp Creek quadrangle, U.S.G.S. 7.5 minute series. Lombard Limestone section measured along a N 20°W traverse, from the northwestern side of the saddle in SE 1/4, SE 1/4, section 6 (between 9,328' hill and Hogback Mountain) to the inferred location of a down-north normal fault. The inferred position of this fault is based on a change in soil color from medium gray to brownish gray and/or a reddish brown color, the absence to noteworthy decrease in dark gray mudstone float, topographic expression, and the absence of any float indicative of Mission Canyon Limestone lithology. This fault was first suggested by Scheedlo (1984).

The Lombard Limestone is best exposed on the northern side of the 9,328' hill. All of the exposed units are overturned, strike approximately N 55°E, and dip an average of 56°NW. The thick covered interval at the base of this section is probably thick as a result faulting, dip variations (increase in the degree of overturning), and/or a gentle to open parasitic fold on the overturned limb.

To reach this area, called "The Notch", turn southwest from the Ruby River Road onto Ledford Creek Road. Drive approximately 3.7 miles to Robb Creek Road, then proceed approximately five miles to a cluster of small buildings (Robb Creek Association Headquarters on county map). Approximately 0.1 mile before the buildings a steep road branches to the northwest, up onto the bench adjacent to Robb Creek; do not attempt to take the road which begins on the northwest side of the fenced pasture adjacent to the buildings as it is deeply incised from gully erosion. Follow the road to the southwest, staying on the bench, to The Notch. It is advisable to confer with the local ranchers at the Robb Creek Association Headquarters regarding exact directions and the condition of the road. Beyond the ranch the road consists of two tire tracks which traverse several meadows, small hills, and streams. Drive to the southwest side of Hogback Mountain (SE 1/4, NE 1/4, section 6). To reach the saddle, hike approximately one mile east-northeast along the stream which empties into Robb Creek from the recent slide on the southwest side of Hogback Mountain.

Unit	Lithology	Ft.
88	COVER: Grassy; shale float; measured to small bump/rib on west side of saddle (at base of 9,328' hill), presumed to represent basal Amsden Formation sandstone...........................	86.5
87	SHALE: Black (N1), weathers to light gray (N7); microcrystalline; thin to medium bedded; beds parallel, planar; fissile to parallel, planar to slightly undulatory, flaggy splitting habit; degree of fissility varies laterally; very thin, parallel, slightly undulatory to disrupted lamina visible on weathered surface; non-fossiliferous; very strong petroliferous odor; slope-former to local ledge-former............	77
86	COVER: Grassy; fossiliferous packstone float..........	32
85	BRACHIOPOD PACKSTONE: Dark yellowish brown (10 YR 4/2), weathers to medium brownish gray (5 YR 5/1); microcrystalline; thick beds with parallel, undulatory, slabby to blocky splitting habit, alternating with medium beds with parallel, undulatory, laminated to flaggy splitting habit; sharp, undulatory contact between thick and medium beds; disarticulated and broken brachiopods, echinoid ossicles, bryozoan debris, few ostracodes, broken pelecypods(?); fossils randomly oriented and distributed; few stylolites; weak petroliferous odor; ledge-former, medium beds less resistant.................................	13
84	COVER: Grassy; dark gray soil; fossiliferous wackestone float.................................	23
83	SPARSE BRYOZOAN WACKESTONE: Pale brown (5 YR 5/2), weathers to light gray (N7); microcrystalline; medium beds with parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with medium to predominantly thin beds with parallel, undulatory to slightly undulatory, fissile to laminated splitting habit; sharp to laterally gradational contact between thin, "platy" beds and subjacent medium, flaggy to slabby beds; sharp, planar to slightly undulatory contact between thin, "platy" beds and superjacent medium, flaggy to slabby beds; trepostome and fenestrate bryozoan fragments, disarticulated and	

broken brachiopods (few whole with geopetal fill), echinoid ossicles; most fossils subparallel to bedding, randomly distributed; small chert nodules; moderate petroliferous odor; ledge-former..................................6

82 COVER: Grassy; medium gray soil; fossiliferous wackestone float...................................9

81 SPARSELY FOSSILIFEROUS WACKESTONE: Pale brown (5 YR 5/2), weathers to medium light gray (N6); microcrystalline; medium beds with parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with medium to predominantly thin beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; trepostome bryozoan fragments, disarticulated and broken brachiopods, echinoid ossicles and fragments; fossils randomly oriented and distributed; few small chert nodules; weak petroliferous odor; ledge-former.......................................4

80 COVER: Grassy; fossiliferous wackestone float.........13

79 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; medium beds with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with medium to predominantly thin beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; many echinoid ossicles and fragments, disarticulated and broken brachiopods, bryozoan fragments, ostracodes; fossils randomly oriented and distributed; bioturbated; burrows?; moderate petroliferous odor; subdued ledge-former.........................3

78 COVER: Grassy; fossiliferous wackestone float..........7

77 BRYOZOAN WACKESTONE: Pale brown (5 YR 5/2), weathers to light gray (N7); microcrystalline; medium beds with parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with medium to predominantly thin beds with parallel, slightly undulatory, fissile to laminated

splitting habit; sharp, slightly undulatory contacts between beds; trepostome and fenestrate bryozoan fragments, disarticulated and broken brachiopods, echinoid ossicles, broken pelecypods(?); most fossils subparallel to bedding, randomly distributed; burrows; few small chert nodules; very weak petroliferous odor; ledge-former..5

76 COVER: Grassy; medium gray soil; fossiliferous wackestone float..................................12

75 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; medium beds with minor parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with medium to predominantly thin beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods, few bryozoan fragments; fossils randomly oriented and distributed; burrows; few small chert nodules; subdued ledge-former..3

74 COVER: Grassy; medium gray soil; fossiliferous wackestone float..................................8

73 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; thin to medium beds with parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with thin beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; many echinoid ossicles and fragments, few disarticulated brachiopods, ostracodes; fossils randomly oriented and distributed; bioturbated; moderate petroliferous odor; ledge-former....................4

72 COVER: Grassy; fossiliferous wackestone float..........3

71 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N6); microcrystalline; thin to medium beds with minor parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with thin beds with parallel, planar to slightly undulatory, fissile to laminated splitting

habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, ostracodes(?), bryozoan debris; fossils randomly oriented and distributed; burrows; small chert nodules; moderate petroliferous odor; ledge-former....................................2

70 COVER: Grassy; medium gray soil; scattered fossiliferous wackestone float........................4

69 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; medium beds with minor slabby splitting habit, alternating with medium beds with parallel, planar to undulatory, fissile to laminated splitting habit; contact at top of fissile/laminated beds sharp and undualtory (up to 2" relief); contact at base of same beds sharp, planar to slightly undulatory; echinoid ossicles, whole (few) and disarticulated brachiopods, disarticulated pelecypods, few bryozoan fragments; horizontal burrows; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former............6

68 COVER: Grassy; fossiliferous wackestone and mudstone float......................................7

67 FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to medium gray (N5); microcrystalline; medium beds with minor slabby splitting habit, alternating with medium beds with parallel, planar to undulatory, fissile to laminated splitting habit; contacts at top of fissile/laminated beds sharp and undulatory (1" to 2" relief); contacts at base of same beds sharp and slightly undulatory; echinoid ossicles, disarticulated brachiopods and pelecypods, small indeterminate horn corals, scattered bryozoan fragments; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former.....................4

66 COVER: Grassy; medium gray soil; scatterd fossiliferous wackestone and mudstone float.........12

65 SPARSELY FOSSILIFEROUS WACKESTONE: Dusky brown (5 YR 2/2), weathers to medium gray (N5); microcrystalline; medium to thick beds with minor slabby splitting habit, alternating with thin to medium beds with

parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory (<1" relief) contacts between beds; echinoid ossicles, disarticulated brachiopods and pelecypods, few small indeterminate corals, scattered bryozoan fragments; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former....................8

64 COVER: Grassy; medium gray soil; scattered fossiliferous wackestone and mudstone float..........5

63 SPARSELY FOSSILIFEROUS WACKESTONE: Dusky brown (5 YR 2/2), weathers to medium gray (N5); microcrystalline; medium to thick beds with minor slabby splitting habit, alternating with thin to medium beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory (<1" relief) contacts between beds; echinoid ossicles, disarticulated brachiopods, scattered bryozoan fragments; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former....................3

62 COVER: Grassy; medium gray to medium light gray soil; fossiliferous wackestone float...........14

61 FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; thick beds with rare slabby to blocky splitting habit, alternating with medium beds with parallel to non-parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods and pelecypods, few bryozoan fragments, few ostracodes(?); fossils randomly oriented and distributed; weak petroliferous odor; ledge-former....................2

60 COVER: Grassy; medium gray soil; fossiliferous wackestone and mudstone float.......................6

59 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; medium to predominantly thick beds with rare slabby splitting habit, alternating with thin to medium beds with parallel to non-parallel,

slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods and pelecypods, bryozoan fragments; fossils randomly oriented and distributed; weak petroliferous odor; ledge-former.....................................5

58 COVER: Grassy; fossiliferous wackestone float..........3

57 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to very light olive gray (5 Y 7/1); microcrystalline; thick beds with rare slabby splitting habit, alternating with medium beds with parallel to non-parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods and pelecypods(?), bryozoan fragments; fossils randomly oriented and distributed; weak to moderate petroliferous odor; ledge-former..................................4

56 COVER: Grassy; fossiliferous wackestone and packstone float......................................7

55 PELECYPOD PACKSTONE: Brownish black (5 YR 2/1), weathers to light olive gray (5 Y 6/1); microcrystalline; medium beds with minor flaggy to slabby splitting habit; rare, thin shaly partings; whole and disarticulated (few broken) pelecypods, disarticulated brachiopods, gastropods, trilobites, few fenestrate bryozoan fragments; fossils randomly oriented and distributed; moderate petroliferous odor; very subdued ledge-former...........................2

54 COVER: Grassy; fossiliferous wackestone and packstone float, some mudstone float.................5

53 PELECYPOD PACKSTONE: Brownish black (5 YR 2/1), weathers to light olive gray (5 Y 6/1); microcrystalline; medium beds with minor flaggy to slabby splitting habit; thin, shaly partings; whole and disarticulated pelecypods, disarticlated brachiopods, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; very subtle ledge-former; poorly exposed.......................2

52 COVER: Grassy; fossiliferous wackestone and packstone float, some mudstone float................16

51 FOSSILIFEROUS PACKSTONE: Brownish black (5 YR 2/1), weathers to light olive gray (5 Y 6/1); microcrystalline; medium beds with minor slabby splitting habit; rare, thin shaly partings; whole (few) and disarticulated pelecypods, disarticulated brachiopods, gastropods, bryozoan fragments; fossils randomly oriented and distributed; moderate petroliferous odor; very subdued ledge-former; poorly exposed........................3

50 COVER: Grassy; fossiliferous wackestone and packstone float, some mudstone float.................8

49 SPARSELY FOSSILIFEROUS WACKESTONE: Dusky brown (5 YR 2/2), weathers to medium gray (N5); microcrystalline; medium beds with minor flaggy to slabby splitting habit; thin, shaly partings; disarticulated brachiopods and pelecypods, echinoid ossicles; fossils randomly oriented and distributed; moderate petroliferous odor; subdued ledge-former..............................3

48 COVER: Grassy fossiliferous wackestone float...........4

47 SPARSELY FOSSILIFEROUS WACKESTONE: Dusky brown (5 YR 2/2), weathers to medium gray (N5); microcrystalline; medium bed with minor flaggy to slabby splitting habit; disarticulated brachiopods and pelecypods, echinoid ossicles and fragments; fossils randomly oriented and distributed; moderate petroliferous odor; subdued ledge-former.............1

46 COVER: Grassy; medium light gray soil; fossiliferous wackestone and mudstone float.........35

45 BRYOZOAN PACKSTONE: Olive gray (5 Y 4/1) to brownish black (5 YR 2/1), weathers to pale grayish orange (10 YR 8/4); microcrystalline; medium beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar contact between medium beds and superjacent thin beds; sharp, planar to undulatory contact between medium beds and subjacent thin beds; dendroid,

indeterminate trepostome and rhabdomesid bryozoans, disarticulated brachiopods, echinoid ossicles and fragments, ostracodes; most fossils parallel to bedding, randomly distributed; moderate petroliferous odor; subdued ledge-former.............3

44 COVER: Grassy; fossiliferous wackestone and packstone float....................................4

43 ECHINOID-BRYOZOAN PACKSTONE: Olive gray (5 Y 4/1), weathers to very light gray (N8) to very pale orange (10 YR 8/2); microcrystalline; medium beds with parallel, slightly undulatory, flaggy splitting habit, alternating with thin beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles (including pentacrinus) and fragments, dendroid, indeterminate trepostome, rhabdomesid, and fenestrate bryozoans, disarticulated brachiopods, ostracodes; most fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued ledge-former.............3

42 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to very light olive gray (5 Y 7/1); microcrystalline; medium beds with parallel, slightly undulatory, flaggy splitting habit, alternating with very thin to thin beds with parallel, slightly undulatory, laminated to predominanatly fissile splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated brachiopods, bryozoan fragments, ostracodes(?); most fossils parallel to bedding, randomly distributed; moderate petroliferous odor; ledge-former; sharp, slightly undulatory to undulatory contacts between units 41 and 43...2

41 ECHINOID-BRYOZOAN PACKSTONE: Olive gray (5 Y 4/1), weathers to very light gray (N8); microcrystalline; medium beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with very thin to thin beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory

contacts between beds; echinoid ossicles (including Pentacrinus) and fragments, indeterminate dendroid trepostome and fenestrate bryozoans, disarticulated brachiopods; most fossils subparallel to bedding; moderate petroliferous odor; subtle ledge-former; sharp, planar contact with unit 40................................2

40 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium to thick beds with parallel, planar to very slightly undulatory, slabby to blocky splitting habit, alternating with very thin to thin beds with parallel, slightly undulatory, laminated to predominantly fissile splitting habit; sharp, slightly undulatory contacts between beds; shaly partings between beds less common; echinoid ossicles and fragments, disarticulated and broken brachiopods, few bryozoan fragments; fossils subparallel to bedding, randomly distributed; many chert nodules and stringers (up to 10" long and 4" high); weak to moderate petroliferous odor; ledge-former...8

39 COVER: Grassy; fossiliferous wackestone and mudstone float.......................................3

38 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium to thick beds with parallel, planar to very slightly undulatory, slabby to blocky splitting habit, alternating with very thin to thin beds with parallel, slightly undulatory, laminated to predominately fissile splitting habit; sharp, planar to slightly undulatory contact between beds; echinoid ossicles, disarticulated brachiopods, few bryozoan fragments; most fossils parallel to bedding; many chert nodules and stringers (up to 14" long and 3" high); moderate petroliferous odor; ledge-former....................3

37 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light olive gray (5 Y 6/1); microcrystalline; thick bed with minor parallel, planar to slightly undulatory, slabby splitting habit, between two medium beds with parallel, planar to

slightly undulatory, laminated to locally fissile splitting habit; sharp, planar to slightly undulatory contacts between beds and between medium, laminated beds and units 36 and 38; echinoid ossicles and partial stems, whole and disarticulated brachiopods; most fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; medium, laminated beds poorly exposed; ledge-former........................2

36 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium to thick beds with parallel, planar to very slightly undulatory, slabby to blocky splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, disarticulated brachiopods, few bryozoan fragments, ostracodes(?); most fossils parallel to bedding, randomly distributed; few small chert nodules; weak to moderate petroliferous odor; ledge former....................4

35 COVER: Grassy; fossiliferous wackestone and mudstone float.......................................8

34 SPARSELY FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium beds with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods, few bryozoan fragments, ostracodes; most fossils parallel to bedding, randomly distributed; moderate petroliferous odor; sharp, slightly undulatory contact with unit 33; ledge-former...3

33 BRACHIOPOD PACKSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; thin bed, with minor parallel, slightly undulatory, laminated splitting habit; many whole and disarticulated brachiopods, few

pelecypods, echinoid ossicles and fragments, ostracodes; most fossils subparallel to bedding, randomly distributed; weak petroliferous odor; ledge-former..0.3

32 BRACHIOPOD WACKESTONE: Dark gray (N3), weathers to light olive gray (5 Y 6/1); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, slabby to blocky splitting habit; few thin to medium beds with parallel, planar to slightly undulatory, fissile to predominantly laminated splitting habit; shaly partings between medium to thick beds more common; many disarticulated and few whole brachiopods, echinoid ossicles and few partial stems, few bryozoan fragments, ostracodes(?); most fossils parallel to subparallel to bedding, randomly distributed; moderate petroliferous odor; subtle to good ledge-former, poorly to moderately well exposed..10

31 COVER: Grassy; fossiliferous wackestone and mudstone float..8

30 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light olive gray (5 Y 6/1); microcrystalline; medium beds with minor parallel, slightly undulatory, flaggy splitting habit; beds separated by shaly parting; echinoid ossicles and partial stems, disarticulated brachiopods, solitary corals (including Siphonophyllia sp.), few bryozoan fragments; most fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued ledge-former................................1.5

29 COVER: Grassy; fossiliferous wackestone and mudstone float..2

28 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with very thin to thin beds with parallel, slightly undulatory, fissile to laminated splittng habit; sharp, slighlty undulatory contacts between beds; echinoid ossicles and fragments,

disarticulated brachiopods, few small solitary corals, few bryozoan(?) fragments; fossils subparallel to bedding, randomly distributed; weak to moderate petroliferous odor; ledge-former; gradational contact with unit 27..3

27 BRACHIOPOD PACKSTONE: Medium dark Gray (N4), weathers to light olive gray (5 Y 6/1); microcrystalline; thin bed with parallel, slightly undulatory, laminated splitting habit (progressively less significant near upper and lower part of bed); transitional contact with units 26 and 27; whole and disarticulated brachiopods, echinoid ossicles and fragments, ostracodes, few disarticulated and broken pelecypods(?); most fossils subparallel to bedding, randomly distributed; weak petroliferous odor; subdued ledge-former..........................0.5

26 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; thick bed with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, underlain by thin(?) bed with parallel, planar to slightly undulatory, fissile splitting habit; sharp, planar to slightly undulatory contact between beds; echinoid ossicles and fragments, disarticulated brachiopods; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; ledge-former....................1

25 COVER: Grassy; fossiliferous wackestone and mudstone float....................................16

24 FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; medium to thick beds with minor parallel, planar to very slightly undulatory, flaggy to predominantly slabby splitting habit, alternating with thin to rarely medium beds with parallel, planar to slightly undulatory, laminated to locally fissile splitting habit; sharp, very slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated brachiopods, ostracodes(?), few bryozoan fragments; most fossils subparallel to bedding; moderate petroliferous odor; subtle ledge-former; poorly exposed.................3

23 COVER: Grassy; mudstone, fossiliferous mudstone and wackestone float........................3

22 FOSSILIFEROUS MUDSTONE: Black (N1), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium beds with very minor parallel, slightly undulatory, flaggy to slabby splitting habit; slightly undulatory shaly parting between beds; disarticulated brachiopods, few indeterminate bryozoan fragments; fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former.............2

21 COVER: Grassy; medium dark gray to dark brownish gray soil; mudstone and fossiliferous mudstone float........................5

20 FOSSILIFEROUS MUDSTONE: Black (N1), weathers to yellowish gray (5 Y 8/1); microcrystalline; thick to predominantly medium beds with very minor parallel, planar to very slightly undulatory splitting habit; planar to slightly undulatory shaly partings between beds; rare thin bed with parallel, planar to slightly undulatory, fissile to laminated splitting habit; echinoid ossicles and few partial stems, disarticulated brachiopods, few bryozoan fragments; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; ledge-former.......................................7

19 COVER: Grassy; dark brownish gray soil; mudstone and fossiliferous mudstone float...........4

18 FOSSILIFEROUS MUDSTONE: Grayish black (N2), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium beds (lacking any internal splitting habit), separated by slightly undulatory shaly partings; echinoid ossicles, disarticulated brachiopods, few bryozoan(?) fragments; fossils randomly oriented and distributed; moderate to strong petroliferous odor; ledge-former.......................................2

17 COVER: Grassy; medium dark gray (N4) soil; fossiliferous mudstone and packstone float..........6

16 FOSSILIFEROUS PACKSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; thick bed with very minor

parallel, slightly undulatory, flaggy to slabby splitting habit; echinoid ossicles, and partial stems, whole and disarticulated pelecypods and brachiopods, bryozoan debris, few gastropods, disarticulated trilobites; fossils subparallel to bedding, randomly distributed, stand with excellent relief on weathered surface; strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 15.....................1

15 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; two medium beds with parallel, planar to slightly undulatory, flaggy splitting habit, alternating with very thin to thin beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp contact between beds; echinoid ossicles and fragments, disarticulated brachiopods, few pelecypods(?), ostracodes; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former; sharp, planar to slightly undulatory contact with unit 14.............2

14 FOSSILIFEROUS PACKSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium and thick beds with minor parallel, slightly undulatory flaggy to predominantly slabby splitting habit, alternating with very thin to thin beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory to rarely planar contacts between beds; echinoid ossicles (including Pentacrinus) and partial stems, few whole and many disarticulated pelecypods and brachiopods, bryozoan fragments; most fossils subparallel to bedding, randomly distributed; very strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 13.....................2

13 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; medium bed with parallel, planar to slightly undulatory, laminated splitting habit; echinoid ossicles, disarticulated brachiopods, few pelecypods(?); most fossils parallel to bedding, randomly distributed; very strong

petroliferous odor; subdued ledge-former, but less resistant than units 12 and 14; sharp, slightly undulatory contact with unit 12...0.5

12 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to medium light gray (N6), microcrystalline; medium bed with very minor parallel, planar to slightly undulatory, flaggy splitting habit; echinoid ossicles, disarticulated brachiopods, ostracodes(?); fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former.................................1

11 COVER: Grassy; medium gray to light gray soil; fossiliferous wackestone and mudstone float.................................24

10 SPARSELY FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to medium gray (N5); microcrystalline; thin to medium beds with minor parallel, slightly undulatory, flaggy splitting habit; beds separated by slightly undulatory to undulatory, shaly partings; few echinoid ossicles; randomly oriented and distributed; strong petroliferous odor; very subdued ledge-former; poorly exposed; sharp, undulatory (2" to 3" relief) contact (largely obscurred) with unit 9....................2

9 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light olive gray (5 Y 6/1); microcrystalline; medium and thin beds with minor parallel, slightly undulatory, flaggy splitting habit; beds separated by slightly undulatory shaly parting; echinoid ossicles and few partial stems, disarticulated brachiopods, bryozoan fragments, disarticulated trilobites, gastropods; fossils randomly oriented and distributed; strong petroliferous odor; ledge-former.......................................1

8 COVER: Grassy; fossiliferous wackestone and mudstone float.......................................1.5

7 BRYOZOAN-CORAL PACKSTONE: Olive gray (5 Y 4/1), weathers to very light gray (N8); microcrystalline; medium beds with very minor parallel, slightly undulatory, flaggy splitting habit; beds separated by

undulatory shaly parting; fenestrate and trepostome bryozoan debris, solitary corals (including Michelinia cf. M. meekana Girty), echinoid ossicles, and partial stems, disarticulated brachiopods; most fossils subparallel to bedding, randomly distributed; weak petroliferous odor; ledge-former; sharp, undulatory contact with unit 6..2

6 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light olive gray (5 Y 5/1); microcrystalline; thin to medium beds with very minor to minor, parallel, slightly undulatory, flaggy splitting habit; beds separated by slightly undulatory shaly partings and rare very thin to thin beds with parallel, planar to slightly undulatory, laminated to fissile splitting habit; sharp contacts between beds; echinoid ossicles and few partial stems, bryozoan debris, disarticulated trilobites, indeterminate orthoconic nautiloid fragments, whole and disarticulated brachiopods; most fossils subparallel to bedding, randomly distributed; strong petroliferous odor; ledge-former...5

5 COVER: Grassy; fossiliferous wackestone and minor mudstone float..................................2

4 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light olive gray (5 Y 5/1; microcrystalline; thin and medium beds with very minor parallel, slightly undulatory, flaggy splitting habit, alternating with very thin beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; echinoid ossicles, many disarticulated and few whole brachiopods, bryozoan debris, few gastropods; fossils subparallel to bedding; moderate petroliferous odor; subdued ledge-former...2.5

3 COVER: Grassy; medium dark gray soil; fossiliferous mudstone float........................65

2 FOSSILIFEROUS MUDSTONE: Brownish black (5 YR 2/1), weathers to light gray (N7); microcrystalline; medium to few thin beds, lacking internal splitting habit; randomly fractured; separated by planar to slightly

undulatory, shaly partings; echinoid ossicles and partial stems, ostracodes; fossils randomly oriented and distributed; horizontal burrows; indeterminate trace fossils on bedding planes; small, augen-shaped to spherical chert nodules; very strong petroliferous odor; very subdued ledge-former; poorly exposed...3

1 COVER: Grassy; dark gray soil; fossiliferous and non-fossiliferous mudstone float; probably structurally thickened; measured to inferred normal fault........................1,087

TOTAL: 1,801.3 feet

VIA. SLIDEROCK MOUNTAIN SECTION I

SW 1/4, SW 1/4, section 24, and NW 1/4, NW 1/4, section 25, T. 10 S., R. 4 W., Spur Mountain quadrangle, U.S.G.S. 7.5 minute series. Partial Lombard Limestone section measured along two west-east traverses, separated by a 680 foot offset 120 feet above the base of the section. The Paleozoic and Mesozoic units east of Sliderock Mountain are all vertical to overturned. A thrust fault separates these overturned units from the right-side-up units in and west of Sliderock Mountain. This fault juxtaposes a thin sliver of the upper part of the Amsden Formation against the upper part of the Lombard; the uppermost Lombard shales and mudstone are faulted out. The lower boundary of this Lombard exposure is controlled by a second thrust fault characterized by much less vertical separation than the other, displaying no more than 100 feet of separation (Scheedlo, 1984). Two smaller thrust faults parallel, and probably splay from, the second thrust fault.

Although the uppermost and lowermost parts of the Lombard are faulted out or covered, the complete, unfaulted, medial section can be measured along two traverses. The lower 120 feet (units 1-12) were measured on the west-northwest facing cliffs at the southeast end of the large amphitheater, at the northern end of Sliderock Mountain. The upper 461 feet were measured on the knob at the base of the east side of Sliderock Mountain, between the heads of Fawn Creek and Dry Fawn Creek. A small saddle divides this knob into two smaller knobs, and may represent another thrust fault, although there is no indication of such a fault in exposures to the immediate north and south.

Sliderock Mountain can only be approached by foot or helicopter. Drive south from Alder, along Ruby River Road (FR 100) to Cottonwood Campground. Continue approximately 4.3 miles to a location midway between Dry Fawn Creek and Dog Creek. Park, cross the Ruby River, and hike northwest on the gentle, eastward-dipping bench toward the large, recent landslide on the east side of Sliderock Mountain. Hike along the northern edge of the landslide to the base of the cliffs, turn north, and continue to the west-facing cliffs at the southeast side of the amphitheater. Note the well exposed, west-dipping thrust fault and east-verging roll-over structure on the north side of the amphitheater.

Unit	Lithology	Ft.
49	SANDSTONE/DOLOMITE: Upper part of Amsden Formation (Amsden Fm.-Quadrant Fm. transition); medium to thick beds with intermittent covered intervals....................	unm.
48	COVER: Grassy; thrust fault...........................	1
47	FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; thick to predominantly medium beds with minor parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin to medium calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, few indeterminate bryozoan fragments, gastropods; fossils randomly oriented and distributed; fractured; strong petroliferous odor; very subdued ledge-former; shale interbeds poorly exposed.....................................	5
46	COVER: Grassy; fossiliferous wackestone float..........	7
45	FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7) to light bluish gray (5 B 7/1); microcrystalline; thin to medium beds with parallel, slightly undulatory, laminated to flaggy splitting habit, alternating with medium to predominantly thin, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, indeterminate small horn corals(?); ostracodes, gastropods; fossils randomly oriented and distributed; fossils locally subparallel to bedding, associated with faint, undulatory, thin lamina visible on weathered surface; few thin brachiopod packstone beds; extensively fractured; very strong petroliferous odor; very subdued ledge-former; poorly to locally moderately well exposed..........................	11
44	COVER: Grassy; fossiliferous wackestone and mudstone float.....................................	3
43	FOSSILIFEROUS WACKESTONE: Olive black (5 Y 2/1), weathers to light gray (N7) to	

very light olive gray (5 Y 7/1); microcrystalline; medium beds with parallel, planar to slightly undulatory, laminated to flaggy splitting habit; few thin, calcareous shale interbeds; echinoid ossicles, few disarticulated and many broken brachiopods, gastropods, ostracodes, few indeterminate bryozoan fragments; fossils randomly oriented and distributed; extensively fractured; very strong petroliferous odor; very subdued ledge-former.......................................7

42 COVER: Grassy; Fossiliferous wackestone and packstone float.......................................3

41 FOSSILIFEROUS PACKSTONE: Light olive gray (5 Y 6/1), weathers to light gray (N7); microcrystalline; no discernable bedding (one thick bed?); parallel, slightly undulatory, flaggy splitting habit; echinoid ossicles, broken brachiopods, indeterminate bryozoan fragments, ostracodes, gastropods; fossils randomly oriented and distributed; minor vuggy porosity along fractures, both with local brownish black (5 YR 2/1) stain; weak to moderate petroliferous odor; subdued ledge-former; poorly exposed.......................3

40 FOSSILIFEROUS MUDSTONE: Very dark yellowish brown (10 YR 3/2), weathers to light gray (N7); microcrystalline; very thin to medium beds, some with parallel, slightly undulatory to undulatory, flaggy splitting habit, alternating with parallel, planar to slightly undulatory, fissile to predominantly laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; sparsely fossiliferous; echinoid ossicles, disarticulated and broken pelecypods and (few) brachiopods, ostracodes; fossils subparallel to bedding, randomly distributed; few stylolites; very strong petroliferous odor; poorly exposed upper contact with unit 41..............................3

39 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weather to medium light gray (N6) to yellowish gray (5 Y 7/2); microcrystalline; thick to very thick massive beds, alternating with thin to medium beds with parallel, slightly

undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; disarticulated and broken brachiopods, many foraminifera, echinoid ossicles, gastropods, ostracodes; fossils randomly oriented and distributed; vuggy porosity along fractures, both with common brownish black (5 Y 2/1) stain; strong petroliferous odor; pronounced ledge-former; sharp, undulatory contact with unit 40.................................9

38 BRACHIOPOD PACKSTONE: Light olive gray (5 Y 5/2), weathers to greenish gray (5 GY 6/1); microcrystalline; medium bed with parallel, slightly undulatory, flaggy splitting habit; predominantly disarticulated and few whole Orthotacean (Strophominidae?) brachiopods, few echinoid ossicles; most fossils parallel to bedding, randomly distributed, tightly packed; very weak petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 39......................2

37 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to very light olive gray (5 Y 7/1); microcrystalline; medium to thick beds with very minor, discontinuous, parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with very thin to thin, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, ostracodes, indeterminate bryozoan fragments; fossils randomly oriented and distributed; weak to moderate petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 38................................6

36 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to light olive gray (5 Y 6/1); microcrystalline; thin beds with slightly undulatory, calcareous shale partings; predominantly echinoid ossicles and fragments, finely broken brachiopods, ostracodes; fossils randomly oriented and distributed, locally clustered; faint, swirled to irregular patchy texture (=bioturbation) on weathered surface; brownish black (5 Y 2/1) stain on some fracture surfaces; strong petroliferous

odor; extensively fractured; subdued ledge-former; sharp, planar to slightly undulatory contacts with units 35 and 37.............3

35 COVER: Grassy; fossiliferous wackestone float..........3

34 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to very light olive gray (5 Y 7/1); microcrystalline; medium to thick beds with very minor, discontinuous, parallel, slightly undulatory, slabby splitting habit, alternating with very thin to medium, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, disarticulated and few broken brachiopods, small horn corals(?), indeterminate ramose bryozoan fragments (up to 1/2" long); fossils randomly oriented and distributed; short, horizontal to inclined burrows; moderate petroliferous odor; few stylolites; ledge-former..................13

33 COVER: Grassy; fossiliferous wackestone float..........7

32 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to very light olive gray (5 Y 7/1); microcrystalline; thick beds with very minor, discontinuous, parallel, slightly undulatory to locally undulatory, slabby splitting habit, alternating with thin to medium, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods (including indeterminate Spiriferids(?) and Productids), few ostracodes, few fenestrate and indeterminate bryozoan fragments, small horn corals(?); fossils randomly oriented and distributed; weak petroliferous odor; ledge-former................8

31 COVER: Grassy; fossiliferous wackestone float..........2

30 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to very light gray (N8); microcrystalline; medium and few thick beds with very minor, parallel, slightly undulatory, flaggy splitting habit, alternating with very thin to few thin, calcareous shale beds; sharp, planar to locally slightly undulatory contacts between beds; echinoid ossicles, disarticulated and few broken brachiopods,

few indeterminate bryozoan fragments, ostracodes, foraminifera; fossils randomly oriented and distributed; pellets(?); few stylolites; short, horizontal to inclined burrows; moderate petroliferous odor; ledge-former..11

29 COVER: Grassy; fossiliferous wackestone and mudstone float..23

28 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium beds, alternating with very thin to thin, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, disarticulated and few broken brachiopods, few indeterminate bryozoan fragments, ostracodes; fossils randomly oriented and distributed; weak petroliferous odor; ledge-former..4

27 COVER: Grassy; scattered fossiliferous and non-fossiliferous mudstone float; dark brownish gray (5 Y 3/1) soil; saddle-former..171

26 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy splitting habit, alternating with silty, thin to medium, calcareous shale beds; sharp, planar contacts between beds; echinoid ossicles, disarticulated and few broken brachiopods, ostracodes(?), gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; very subdued ledge-former..8

25 COVER: Grassy; fossiliferous mudstone float; minor fossiliferous wackestone float................13

24 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy splitting habit, alternating with silty thin to medium, calcareous shale beds; sharp, planar contacts between beds; echinoid ossicles, disarticulated and few broken brachiopods, gastropods; fossils randomly oriented and

distributed; moderate petroliferous odor; very subdued ledge-former............................7

23 COVER: Sparsely fossiliferous wackestone, fossiliferous and non-fossiliferous mudstone float.......................................6

22 SPARSELY FOSSILIFEROUS WACKESTONE: Grayish black (N3), weathers to medium light gray (N6); microcrystalline; thick beds with very minor, parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with thin to thick, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, gastropods, ostracodes(?); fossils randomly oriented and distributed; fossils in fissile beds subparallel to bedding; weak to moderate petroliferous odor; subdued ledge-former; poorly to moderately well exposed.............................10

21 COVER: Grassy; non-fossiliferous and fossiliferous mudstone float........................14

20 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light olive gray (5 Y 6/1); microcrystalline; medium to thick beds with discontinuous, parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with silty, thin to medium, calcareous shale beds; echinoid ossicles and fragments, disarticulated brachiopods; fossils subparallel to bedding to locally randomly oriented, randomly distributed; moderate petroliferous odor; very subdued ledge-former; poorly exposed........................6

19 COVER: Sparsely fossiliferous wackestone and fossiliferous mudstone float........................4

18 SPARSELY FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; thick beds with minor parallel, planar to slightly undulatory, flaggy to predominantly slabby splitting habit, alternating with silty, medium to thick, calcareous shale beds; sharp, planar contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, ostracodes, small corals (including indeterminate dissepimented horn corals);

fossils subparallel to bedding, randomly distributed; fissile beds brachiopod-rich (including whole and disarticulated _Inflatia_ cf. _I._ _obsoletus_ Easton, large _Chonetes_ sp.); moderate petroliferous odor; subdued ledge-former..........................9

17 COVER: Sparsely fossiliferous wackestone and fossiliferous mudstone float..........................8

16 SPARSELY FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; slightly silty; thick beds with minor parallel, planar to slightly undulatory, flaggy to predominantly slabby splitting habit, alternating with medium to thick, silty beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar to locally slightly undulatory contacts between beds; echinoid ossicles (wide range of sizes), disarticulated and broken brachiopods, partial trilobites, few broken gastropods(?), ostracodes; most fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; subdued ledge-former..................................10

15 COVER: Fossiliferous wackestone and mudstone float..6

14 SPARSELY FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to light gray (N7); beds with minor parallel, planar to slightly undulatory, flaggy to predominantly slabby splitting habit, alternating with medium to thick, silty beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar to locally slightly undulatory contacts between beds; echinoid ossicles (wide range of sizes), disarticulated and broken brachiopods, partial trilobites, small indeterminate horn corals, few gastropods; most fossils subparallel to bedding, randomly distributed; many additional ostracodes, and whole and disarticulated brachiopods (including indeterminate Productids, large _Chonetes_ sp.(?)) in fissile beds (most fossils parallel to bedding); moderate to strong petroliferous odor; ledge- to subdued

ledge-former..22

13 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; thick beds with minor parallel, planar to locally undulatory, slabby splitting habit, alternating with very thin to thin (few medium) beds with parallel, planar to locally undulatory, fissile to laminated splitting habit, sharp, predominantly planar contacts between beds; echinoid ossicles and fragments, few whole and many disarticulated and broken brachiopods, ostracodes(?), gastropods; indeterminate, finely comminuted fossil debris; fossils randomly oriented to subparallel to bedding, randomly distributed; faint, thin to medium, planar to locally undulatory lamina locally visible on weathered surface; swirled texture (=bioturbation) and horizontal burrows common in many thick beds; moderate petroliferous odor; ledge- to subdued ledge-former; moderately well to well exposed; sharp, planar to slightly undulatory contact with unit 12; transition into unit 14 characterized by rapid thickening-upward of fissile/laminated beds over a 10' interval............................41

[NOTE: Offset 680 feet south along unit 12-unit 13 contact to exposure on small knob at base of east side of Sliderock Mountain, adjacent to and just north of large recent landslide; NW corner of NE 1/4, NW 1/4, NW 1/4, section 25, T. 10 S., R. 4 W.]

12 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to medium gray (N5); microcrystalline; slightly silty; medium to thick beds with minor discontinuous, parallel, planar to slightly undulatory, flaggy to slabby splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, broken pelecypods and brachiopods, ostracodes, few fenestrate bryozoan fragments; fossils parallel to bedding, randomly distributed; faint, slightly disturbed, very thin lamina locally visible on weathered surface; strong petroliferous odor; very subdued ledge-former; poorly exposed...8

11 COVER: Fossiliferous and non-fossiliferous mudstone float....................................10

10 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to medium gray (N5); microcrystalline; slightly silty; medium to thick beds with minor discontinuous, parallel, planar to slightly undulatory, flaggy to slabby splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, broken pelecypods(?) and brachiopods; fossils parallel to bedding, randomly distributed; faint, slightly disturbed, very thin lamina locally visible on weathered surface; strong petroliferous odor; poorly exposed...........5

9 COVER: Fossiliferous and non-fossiliferous mudstone float....................................7

8 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to very light gray (N8); microcrystalline; thick beds with minor, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with medium beds (few thin) with parallel, undulatory, fissile splitting habit; sharp, planar to slightly undulatory contacts between beds; sparsely fossiliferous; echinoid ossicles, disarticulated and broken pelecypods, ostracodes; fossils randomly oriented and distributed; many horizontal to inclined, straight to hooked burrows; moderate petroliferous odor; extensively fractured; very subdued ledge-former; poorly exposed..........10

7 COVER: Fossiliferous and non-fossiliferous mudstone float....................................4

6 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weather to medium gray (N5); microcrystalline; slightly silty; medium to thick beds with minor discontinuous, parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with medium beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles, broken brachiopods, ostracodes, few fenestrate bryozoan fragments; fossils parallel to bedding, randomly distributed; faint, slightly undulatory and disturbed,

very thin lamina locally visible on weathered surface; strong petroliferous odor; medium/thick beds poorly exposed, fissile/laminated beds very poorly exposed..........19

5 SPARSELY FOSSILIFEROUS WACKESTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; thick beds with parallel, planar to slightly undulatory, slabby to blocky splitting habit, alternating with thin to predominantly medium beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; some lateral variations in splitting habit in thick beds; echinoid ossicles, disarticulated and broken brachiopods, ostracodes, few bryozoan(?) fragments; fossils randomly oriented to locally subparallel to bedding, randomly distributed; moderate petroliferous odor; ledge-former; gradational contact with unit 6.....................9

4 ECHINOID WACKESTONE: Olive gray (5 Y 4/1), weathers to light olive gray (5 Y 6/1); microcrystalline; medium to thick beds with very minor parallel, slightly undulatory, slabby splitting habit, alternating with thin to medium beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; many echinoid ossicles, disarticulated and broken brachiopods, few fenestrate bryozoan fragments, ostracodes, few partial trilobites, much finely comminuted fossil debris; fossils randomly oriented and distributed; few burrows(?); moderate petroliferous odor; ledge-former; gradational contact with unit 5..7

3 SPARSELY FOSSILIFEROUS WACKESTONE: Grayish black (N2), weathers to light olive gray (5 Y 6/1); microcrystalline; medium to very thick beds (up to 4' thick) with absent to minor parallel, slightly undulatory, slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, disarticulated and

broken brachiopods, bryozoan fragments (including indeterminate fenestrates), ostracodes; fossils subparallel to bedding, randomly distributed; few scattered, small clusters of fossils in discrete intervals; local swirled texture (=bioturbation); large chert nodules/stringers in upper part (up to 3' long, 1.5' wide); moderate petroliferous odor; ledge-former....................13

2 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; thick to predominantly medium beds very minor, parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel to non-parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to locally undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods (few whole) and pelecypods, ostracodes, broken gastropods(?); fossils randomly oriented to subparallel to bedding in medium/thick beds, subparallel to parallel to bedding in thin/medium beds, randomly distributed; few short, horizontal burrows; local, slightly swirled texture (=bioturbation); extensively fractured in lower part; strong petroliferous odor; ledge-former....................28

1 COVER: Talus apron at base of cliffs; fossiliferous mudstone and wackestone, and non-fossiliferous mudstone float....................unm.

TOTAL: 561.0 feet

VIB. SLIDEROCK MOUNTAIN SECTION II

NE 1/4, SW 1/4, SW 1/4, SW 1/4, section 24, T. 10 S., R. 4 W., Spur Mountain quadrangle, U.S.G.S. 7.5 minute series. Partial Lombard Limestone section measured on the eastern end of the north-facing cliffs on the northern side of Sliderock Mountain. This section was first described, using Big Snowy Formation nomenclature, by Gealy (1953). This cliff section has a stratigraphically normal-up orientation and is only lacking exposure of the lowermost Lombard. The lower 435 feet of this section crop out in vertical to near vertical cliffs which cannot be safely measured without the aid of ropes. The following measured section is largely based on, and concurs with, Gealy's work, although a few minor variations are noted. Where direct sampling and observation was possible, detailed observations are included with, or modify, Gealy's observations. Gealy (1953) did not mention where on the cliffs his section was measured. Most of the lower 435 feet of this section (cliffs) was inaccessible to this writer, so modifying and additional comments are based on observations and measurements made along the eastern end of the cliffs where a juxtaposed, steep talus slope permits close, although usually indirect observation; "safe" access to the cliffs is possible at a few levels.

Gealy's measurements of the uppermost Lombard shale sequence (unit 14), well exposed on an accessible slope above the cliffs, are too low and seem to have disregarded the covered interval (units 12 and 13) below the shales. Some structural complication involving unit 11 is suggested by the Early and Late Mississippian ages provided by corals in the upper part of the unit. The presence of Siphonophyllia sp. and Amplexizaphrentis sp. supports a Lombard Limestone interpretation for these rocks, however the presence of Vesiculophyllum sp. suggests that a thrust slice of Madison Limestone, probably Lodgepole Limestone, is also present (Sando, personal communication, 1985). The degree of structural complication is unknown.

Unit	Lithology	Ft.
15	COVER: Grassy; Dark grayish red (10 R 3/2) to dark brownish gray (5 YR 3/1) sandy soil; scattered shale and siltstone to very fine grained sandstone float; basal Amsden Formation..................................	unm.
14	SHALE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; silty; very thin to medium beds with parallel, planar to slightly undulatory, fissile to locally laminated splitting habit; non-fossiliferous; very strong petroliferous odor; slope-former..................	55
13	COVER: Grassy; Brownish black (5 YR 2/1) soil; scattered shale float.........................	93.5
12	COVER: Grassy; abrupt change to gentle slope; Brownish gray (5 YR 4/1) soil; predominantly fossiliferous wackestone float, minor shale float from above.................	82
11	FOSSILIFEROUS WACKESTONE/PACKSTONE: Olive black (5 Y 2/1) to olive gray (5 Y 4/1), weathers to yellowish gray (5 Y 7/2); microcrystalline; thick beds with minor parallel, slightly undulatory to locally undulatory, slabby to blocky splitting habit; thin shaly partings between beds; echinoid ossicles and partial stems, disarticulated and broken brachiopods (including _Spirifer_ _brazerianus_ Girty, _Anthracospirifer_ _curvilateralis_ Easton, _Antiquatonia_ sp., _Diaphragmus_ cf. _D._ _cestriensis_ Worthen, _Flexaria_ sp., _Inflatia_ cf. _I._ _obsoletus_ Easton, _Inflatia_ sp., _Composita_ cf. _C._ _sulcata_ Weller, and many large, indeterminate Productids; all fossils retrieved from float at base of exposed ledges), bryozoans (including indeterminate fenestrate, Cystoporid, and indeterminate ramose forms), colonial and solitary corals (including _Amplexizaphrentis_ sp., _Siphonophyllia_ sp., _Vesiculophyllum_ sp., indeterminate Amplexoid coral), ostracodes, disarticulated and partial trilobites; fossils randomly oriented to locally subparallel to bedding, stand with moderate relief on weathered surface; swirled texture (=bioturbation); fossil density very high (=packstones) within	

discrete intervals within some wackestone beds; moderate petroliferous odor; ledge-former..18

10 FOSSILIFEROUS WACKESTONE/PACKSTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; thin to medium beds with minor parallel, planar to slightly undulatory, flaggy splitting habit; very thin to thin shale partings between many beds; slightly silty; echinoid ossicles and fragments, disarticulated brachiopods and pelecypods, ostracodes, few indeterminate bryozoan(?) fragments; fossils subparallel to bedding to locally randomly oriented, randomly distributed; few packstone beds in upper part of unit; moderate petroliferous odor; subdued ledge-former................................61.5

9 FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium to thick beds (few very thick beds) with minor parallel, slightly undulatory to locally undulatory, flaggy to blocky splitting habit, alternating with thin to locally medium shale beds; sharp, slightly undulatory contacts between beds; echinoid ossicles and partial stems, disarticulated and broken brachiopods, indeterminate corals, partial trilobites, indeterminate bryozoan fragments; fossils randomly oriented to locally subparallel to bedding, randomly distributed; moderate petroliferous odor; ledge-former......................................73.5

8 MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; thin to medium beds; slightly undulatory shale partings between beds; non-fossiliferous(?); many elongate chert nodules; subdued ledge-former..12

7 MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; slightly silty; thin to thick beds; thin, planar to slightly undulatory shale partings; non-fossiliferous(?); few elongate chert nodules and dolomitic limestone bands; ledge-former..65

6 MUDSTONE: Dark gray (N3), weathers to light gray (N7); microcrystalline; slightly

silty; thin to medium (few thick) beds with minor parallel, planar to predominantly slightly undulatory, flaggy splitting habit, alternating with very thin to thin beds with parallel, slightly undulatory, laminated to predominantly fissile splitting habit; sharp contacts between beds; non-fossiliferous(?); chert nodules; few thin bands of dolomitic limestone; subdued ledge-former to local ledge-former..................45.5

5 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; thin to predominantly medium beds with minor parallel, planar to slightly undulatory, flaggy splitting habit; shale partings; sparsely fossiliferous; few echinoid ossicles, disarticulated and broken brachiopods, indeterminate fossil debris; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former...........92

4 MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; slightly silty; medium to thick beds with minor discontinuous, parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with very thin to thin shale beds; sharp, slightly undulatory to locally undulatory contacts between beds; non-fossiliferous(?); several elongate chert nodules and stringers; few very thin to thin dolomitic(?) beds; subdued ledge-former to local ledge-former..................41.5

3 FOSSILIFEROUS MUDSTONE: Dark gray (N3), weathers to medium light gray (N6); microcrystalline; slightly silty; medium to thick (few thin) beds with minor discontinuous, parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium shale beds; sharp, planar to slightly undulatory contacts between beds; few disarticulated and broken brachiopods, echinoid ossicles, ostracodes(?); fossils subparallel to bedding, randomly distributed; moderate to strong petroliferous odor; ledge-former...................26

2 FOSSILIFEROUS MUDSTONE: Medium dark gray (N4), weathers to medium light gray (N6); microcrystalline; thick to very thick beds

with discontinuous, parallel, planar to slightly undulatory, slabby splitting habit, alternating with very thin to medium shale beds; sharp, planar to slightly undulatory contacts between beds; sparsely fossiliferous; echinoid ossicles and fragments, ostracodes, broken brachiopods and gastropods(?); fossils subparallel to bedding, randomly distributed; many horizontal burrows; moderate petroliferous odor; ledge-former..........18

1 COVER: talus apron at base of Lombard cliff sequence.......................................unm.

TOTAL: 683.5 feet

VII. SNOWCREST MOUNTAIN SECTION

SE 1/4, NE 1/4, section 1, T. 10 S., R. 4 W., and SW 1/4, NW 1/4, section 6, T. 10 S., R. 3 W., Spur Mountain quadrangle, U.S.G.S. 7.5 minute series. Partial Lombard Limestone section measured on south-facing cliffs and slope adjacent to the northern arm of an extensive, recent landslide, southwest of Snowcrest Mountain. The section was measured along a south-southwest to north-northeast traverse, from the talus field at the base of the cliffs, to the low relief saddle just northwest of the knob (summit elevation 9,069') in the northwest quarter of section 6.

The Lombard is well exposed as near-vertical to vertical cliffs and ledges which impart a stairstep appearance to the cliffs. A few talus-filled chutes located near the eastern end of the cliffs can be utilized for relatively safe access up the cliffs, although a few short climbs are required. The lowermost Lombard is buried under talus, while the uppermost Lombard is soil- and talus-covered and/or missing because of erosion. The principal crest of the Snowcrest Range, trending north-south and located just east of the cliffs, is coincident with the hinge line of the large, east-verging, overturned anticline which characterizes this range. The Lombard Limestone is the oldest unit exposed in the core of the anticline in the northern part of the range. The Amsden Formation is exposed on the overturned, eastern limb of the anticline, very near to the hinge line, suggesting that only a minimal amount of Lombard has been lost by erosion. This measured section, therefore, is believed to be relatively complete, with the exception of the missing and/or buried lowermost and uppermost parts of the Lombard, which are believed to be of minimal thickness. The Kibbey is not exposed here, and the Mission Canyon is thrust over the Lombard, abruptly truncating the cliff sequence to the west.

To reach this location, drive south from Alder along Ruby River Road (FR 100) to the Lewis Creek jeep road, approximately 0.5 mile northwest of the Vigilante guard station. Hike or drive southwest up this jeep road to the hunters camp at the end (approximately 2.4 miles). Hike west along the Snowcrest trail, which begins at the southwest end of the camp, to the summit of Snowcrest Mountain. Turn southwest, and hike approximately 0.8 mile to the east end of the northern arm of the large landslide. The easiest approach to the base of the cliffs is from the east-southeast side of the easternmost end of the landslide arm.

Unit	Lithology	Ft.
72	COVER: Grassy slope; some fossiliferous and non-fossiliferous mudstone float, and minor sparsely fossiliferous wackestone float; medium brownish gray (5 YR 5/1) to brownish gray (5 YR 4/1) soil............................	228
71	SPARSELY FOSSILIFEROUS WACKESTONE: Dark brownish gray (5 YR 3/1), weathers to light brownish gray (5 YR 6/1); microcrystalline; slightly dolomitic(?); poorly exposed; medium to thick beds, alternating with thin beds with parallel, undulatory, laminated splitting habit; disarticulated and broken brachiopods, echinoid ossicles and fragments, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; very subdued ledge-former (negligible relief)....................	7
70	COVER/SPARSELY FOSSILIFEROUS WACKESTONE: Grassy slope; abundant, small sparsely fossiliferous wackestone, and fossiliferous and non-fossiliferous mudstone float; few small, scattered outcrops of sparsely fossiliferous wackestone; outcrops have negligible relief, contain echinoid ossicles and fragments, disarticulated and broken brachiopods, gastropods, ostracodes(?); few outcrops with slightly undulatory to undulatory, flaggy to slabby splitting habit; most outcrops massive, slightly dolomitic(?)............................	37
69	SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light brownish gray (5 YR 6/1); microcrystalline; thick beds with very minor, parallel, slightly undulatory to undulatory, slabby splitting habit, alternating with thin to medium beds with parallel, undulatory, laminated to fissile splitting habit; sharp, undulatory contacts between beds; echinoid ossicles, and fragments, disarticulated brachiopods, few gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former..................................	8
68	FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light brownish gray (5 YR 6/1); microcrystalline; slightly dolomitic(?); very thick bed with discontinuous, parallel, undulatory, slabby	

splitting habit, between two medium beds with parallel, slightly undulatory, laminated splitting habit; sharp, slightly undulatory contacts between beds; disarticulated and broken brachiopods, echinoid ossicles, few bryozoan(?) fragments; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; sharp, undulatory contact with unit 69.......................................4

67 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; thick beds with minor, discontinuous, parallel, undulatory, flaggy splitting habit, alternating with thin to predominantly medium calcareous shale beds; sharp, slightly undulatory contacts between beds; disarticulated and broken brachiopods (few whole), echinoid ossicles, ostracodes, bryozoan(?) fragments; moderate petroliferous odor; ledge-former; sharp, undulatory contact with unit 68......................9

66 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; thick beds with minor, discontinuous, parallel, undulatory, flaggy splitting habit, alternating with thin, calcareous shale beds; sharp, slightly undulatory contacts between beds; whole and disarticulated and few broken brachiopods, echinoid ossicles, ostracodes(?), few bryozoan(?) fragments; fossils randomly oriented and distributed; weak petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 67...5.5

65 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; slightly silty; slightly dolomitic(?); medium to thick beds with rare parallel, slightly undulatory, flaggy splitting habit, alternating with thin beds with parallel, slightly undulatory to locally planar, laminated to fissile splitting habit; echinoid ossicles and few fragments, disarticulated brachiopods, ostracodes; fossils randomly oriented and distributed, locally subparallel to bedding; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 66..............................8

64 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to medium light gray (N6); microcrystalline; slightly silty; slightly dolomitic(?); very thick to predominantly thick beds with minor parallel, slightly undulatory to undulatory, slabby splitting habit, alternating with thin to (few) medium beds with parallel, undulatory, laminated to locally fissile splitting habit; sharp, undulatory contacts between beds; echinoid ossicles and fragments, whole and disarticulated brachiopods, gastropods, ostracodes(?); fossils randomly oriented and distributed; moderate to strong petroliferous odor; ledge-former; sharp, undulatory contact with unit 65.......................................11

63 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; very thick bed with parallel, slightly undulatory to undulatory, slabby splitting habit; few echinoid ossicles, disarticulated brachiopods; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; very subdued ledge-former; sharp, undulatory contact with unit 64.......................................3

62 SPARSELY FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; slightly silty; three thick beds, alternating with thin calcareous shale beds; sharp, slightly undulatory contacts between beds; echinoid ossicles and fragments, broken and few disarticulated braciopods; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; very subdued ledge-former; sharp, planar contact with unit 63................................4

61 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to medium light gray (N6); microcrystalline; slightly silty; very thick(?) bed with parallel, undulatory, laminated to locally fissile splitting habit; few disarticulated brachiopods, few echinoid ossicles; fossils subparallel to parallel to bedding, randomly distributed; very strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 62................................4

60 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; slightly silty; slightly dolomitic; thick to very thick (one 4' thick) beds with rare parallel, slightly undulatory, slabby splitting habit, alternating with thin beds with parallel, undulatory, laminated to fissile splitting habit; sharp, undulatory contacts between beds; echinoid ossicles, whole and disarticulated brachiopods, gastropods, ostracodes; fossils randomly oriented and distributed, brachiopods in all beds; few random burrows(?); strong petroliferous odor; ledge-former....................9.5

59 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; two thick beds with very minor, discontinuous, parallel, undulatory, slabby splitting habit, alternating with thin and medium beds with parallel, undulatory, laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, whole and disarticulated brachiopods, few bryozoan(?) fragments, few gastropods; fossils randomly oriented and distributed, slight lateral variation in fossil density; brachiopods in all beds; moderate petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 60...6

58 SPARSELY FOSSILIFEROUS WACKESTONE: Dark Olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; slightly silty; slightly dolomitic; thick beds, alternating with thin beds with parallel, slightly undulatory, laminated to fissile splitting habit; sharp, undulatory contacts between beds; disarticulated brachiopods, echinoid ossicles; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; sharp, undulatory contact with unit 59.....................5

57 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; medium to thick beds with minor, parallel, slightly undulatory, slabby splitting habit, alternating with thin to predominantly medium beds with parallel, slightly

undulatory, laminated to fissile splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles and fragments, few disarticulated and broken brachiopods, few partial trilobite molds, disarticulated pelecypods(?), few small fenestrate bryozoan fronds; slightly swirled texture (= bioturbation); fossils subparallel to bedding and distributed; several small chert nodules; strong petroliferous odor; ledge-former; sharp, undulatory contact with unit 58.....................7

56 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; thick beds with minor, parallel, slightly undulatory, slabby splitting habit, alternating with medium beds with parallel, planar to predominantly slightly undulatory, laminated splitting habit; sharp, undulatory contacts between beds; echinoid ossicles and fragments, variably sized whole and disarticulated brachiopods, disarticulated and partial trilobites, ostracodes; fossils randomly oriented and distributed; few chert nodules; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 57............14

55 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to medium brownish gray (5 YR 5/1); microcrystalline; slightly silty; slightly dolomitic; medium to thick beds with very minor, parallel, planar to slightly undulatory, flaggy splitting habit, alternating with medium beds with parallel, undulatory, laminated to fissile splitting habit; sharp, planar to slightly undulatory contacts between beds; sparsely fossiliferous; echinoid ossicles, disarticulated and broken brachiopods and few pelecypods(?), gastropods; fossils randomly oriented and distributed; many randomly oriented burrows; moderate petroliferous odor; ledge- to subdued ledge-former; sharp, slightly undulatory contact with unit 54................................10

54 FOSSILFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to medium brownish gray (5 YR 5/1); microcrystalline; slightly silty; medium beds alternating

with medium beds with parallel, slightly undulatory, laminated to fissile splitting habit; sharp, slightly undulatory contacts between beds; sparsely fossiliferous; echinoid ossicles, disarticulated brachiopods; fossils subparallel to bedding, randomly oriented; strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 55....................6

53 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; silty to (fine) sandy; thick beds with minor parallel, slightly undulatory, slabby to locally flaggy splitting habit, alternating with medium beds with parallel, undulatory, laminated to locally fissile splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods and few pelecypods, few bryozoan(?) fragments, ostracodes, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge- to subdued ledge-former; sharp, planar contact with unit 54.......................15

52 FOSSILIFEROUS MUDSTONE: Grayish black (N2) to black (N1), weathers to yellowish gray (5 Y 8/1); microcrystalline; silty; medium to (few) thick beds with parallel, slightly undulatory to predominantly planar, flaggy splitting habit, alternating with thick to (few) very thick, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; sparsely fossiliferous; broken echinoid ossicles, disarticulated and broken brachiopods (including Inflatia sp., Spirifer sp. (possibly S. brazerianus Girty), Antiquatonia? sp.), ostracodes, gastropods; fossils subparallel to bedding to locally randomly oriented, randomly distributed; small, horizontal to slightly inclined, straight to hooked burrows; strong to very strong petroliferous odor; medium/thick beds form ledges, shales poorly exposed (slope-former).....................................14

51 SPARSELY FOSSILIFEROUS WACKESTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; silty; medium beds with parallel, planar to

undulatory, flaggy splitting habit, alternating with thick, calcareous shale beds; sharp, planar contacts between beds; many echinoid ossicles and fragments, whole and disarticulated brachiopods (including indeterminate Productids, possibly <u>Inflatia</u> sp.?), ostracodes, gastropods (up to 1" long); fossils randomly oriented in flaggy beds, subparallel to bedding in shale beds, randomly distributed; strong to very strong petroliferous odor; medium beds form ledges, shales poorly exposed (slope-former)....................................8

50 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to medium gray (N5); microcrystalline; medium to thick beds with very minor, parallel, slightly undulatory, slabby splitting habit, alternating with thin to medium, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and many fragments, bryozoan fragments, small whole pelecypods, few small disarticulated brachiopods, gastropods; fossils subparallel to bedding, randomly distributed; local swirled texture (=bioturbation); strong petroliferous odor; ledge-former; contact with unit 51 obscurred by talus.....................9

49 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy splitting habit, alternating with medium to predominantly thin beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; sparsely fossiliferous; echinoid ossicles, disarticulated brachiopods and few pelecypods(?), rare gastropod; fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 50...5

48 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to medium gray (N5) to grayish orange (10 YR 7/4); microcrystalline; medium to predominantly

thick beds with minor, parallel, slightly undulatory, slabby splitting habit, alternating with thin, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, few whole and many disarticulated pelecypods, disarticulated brachiopods, few bryozoan fragments, ostracodes, few gastropods; fossils subparallel to bedding, randomly distributed, some silicified; few stylolites, few randomly oriented burrows; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 49..13

47 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to medium gray to grayish orange (10 YR 7/4); microcrystalline; medium to thick beds with very minor, parallel, slightly undulatory, slabby splitting habit, alternating with thin to medium, calcareous shale beds; sharp, planar to slightly undulatory contacts betweeen beds; echinoid ossicles and fragments, whole and disarticulated pelecypods, disarticulated brachiopods, gastropods, few bryozoan fragments; most fossils subparallel to parallel to bedding, randomly distributed; local swirled texture (=bioturbation); few randomly oriented burrows; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 48.....................7

46 FOSSILIFEROUS MUDSTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; medium to thick beds with minor parallil, slightly undulatory to locally undulatory, slabby splitting habit, alternating with medium to predominantly thin, calcareous shale beds; sharp, slightly undulatory contacts between beds; few echinoid ossicles, disarticulated brachiopods and (few) pelecypods, ostracodes(?); fossils randomly oriented to locally subparallel to bedding, randomly distributed; few horizontal to inclined burrows; few stylolites; strong petroliferous odor; ledge-former; contact with unit 47 obscurred by talus...................16

45 SPARSELY FOSSILIFEROUS WACKESTONE: Medium olive gray (5 Y 5/1), weathers to light gray (N7); microcrustalline; medium to thick beds with rare, parallel, slightly undulatory splitting habit, alternating with medium beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar contacts between beds; echinoid ossicles and fragments, ostracodes, few gastropods, disarticulated and few whole brachiopods, few disarticulated pelecypods; fossils randomly oriented and distributed; few, horizontal to slightly inclined, dendroid burrows (1/20" diameter); few stylolites; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 46.............8

44 FOSSILIFEROUS MUDSTONE: Olive gray (5 Y 4/1), weathers to yellowish gray (5 Y 8/1); microcrystaliine; medium beds with rare parallel, slightly undulatory, flaggy splitting habit, altrenating with medium to predominantly thin, calcareous shale beds; sharp, planar to slightly undulatory contacts between beds; ostracodes, echinoid ossicles, few (sparry calcite-filled) whole and disarticulated brachiopods, broken gastropods(?); fossils randomly oriented and distributed; few horizontal to inclined burrows; strong petroliferous odor; ledge-former; sharp, planar contact with unit 45...10

43 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; medium to thick beds with minor, discontinuous, parallel, slightly undulatory, flaggy to slabby splitting habit, alternating with medium to predominantly thin beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, disarticulated and (few) whole brachiopods (few with geopetal fill), few disarticulated pelecypods, ostracodes, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; contact with unit 44 obscurred by talus...................10

42 FOSSILIFEROUS MUDSTONE: Olive gray (5 Y 4/1), weathers to mdeium light gray (N6); microcrystalline; thick to predominantly medium beds with rare parallel, slightly undulatory, flaggy splitting habit, alternating with medium to predominantly thin beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; whole and disariculated brachiopods (many Productids), echinoid ossicles, few gastropods; fossils randomly oriented and distributed; few randomly oriented burrows; few stylolites; strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 43....................11

41 FOSSILIFEROUS GRAINSTONE: Light olive gray (5 Y 6/1) to very pale yellowish brown (10 YR 7/2), weathers to pale grayish orange (10 YR 8/4); microcrystalline; slightly dolomitic; very thick, massive beds; very indurate; many echinoid ossicles and few partial stems, many fenestrate and indeterminate bryozoan fragments, disarticulated and broken brachiopods, few gastropods, ostracodes; fossils randomly oriented and distributed; very weak petroliferous odor; cliff-former; sharp, planar contact with unit 42...31

40 MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; medium to thick beds with rare parallel, planar to slightly undulatory, flaggy splitting habit, alternating with medium beds with parallel, planar to slightly undulatory, laminated to fissile splitting habit; sharp, planar to slightly undulatory contacts between beds; strong petroliferous odor; very subdued ledge-former; sharp, planar contact with unit 41................................6

39 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; thick bed between two medium, silty, calcareous shale beds; sharp, planar contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, gastropods; fossils randomly oriented and distributed; weak

petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 40............3

38 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; slightly silty; medium beds alternating with thin to medium beds with parallel, planar, laminated to fissile splitting habit; sharp, planar contacts between beds; sparsely fossiliferous; echinoid ossicles, small disarticulated and broken brachiopods; fossils subparallel to bedding, randomly distributed; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 39........................4

37 MUDSTONE: Brownish black (5 YR 2/1), weathers to light gray (N6); microcrystalline; slightly silty; medium to thick beds with rare parallel, slightly undulatory, flaggy splitting habit, alternating with medium beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar contacts between beds; strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 38......................7

36 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; slightly silty; thick beds with minor, parallel, planar to predominantly slightly undulatory, slabby to locally flaggy splitting habit, alternating with medium to (few) thin beds with parallel to non-parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, small disarticulated and broken brachiopods, ostracodes(?); fossils randomly oriented and distributed; few horizontal to inclined burrows(?); moderate petroliferous odor; ledge-former; sharp, planar contact with unit 37........................12

35 MUDSTONE: Brownish black (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; slightly silty; medium beds with rare discontinuous, parallel, planar flaggy splitting habit, alternating with thin to medium beds with parallel,

planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar to locally slightly undulatory contacts between beds; strong petroliferous odor; subdued ledge-former; sharp, planar contact with unit 36..................8

34 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to yellowish gray (5 Y 8/1); microcrystalline; slightly silty; thick beds with minor parallel, planar to slightly undulatory, slabby splitting habit, alternating with medium beds with parallel, undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; echinoid ossicles, disarticulated brachiopods, few broken and disarticulated pelecypods(?); fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; contact with unit 35 obscurred by talus..............7

33 FOSSILIFEROUS MUDSTONE: Dark brownish gray (5 YR 3/1), weathers to medium light gray (N6); microcrystalline; slightly silty; medium to thick beds with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to predominantly medium beds with parallel, planar to undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; sparsely fossiliferous; echinoid ossicles, ostracodes, broken brachiopods; fossils subparallel to bedding, randomly distributed; small, grayish black (N2) wisps parallel to bedding; few horizontal burrows; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 34................................9

32 MUDSTONE: Brownish black (5 YR 2/1), weathers to medium light gray (N6); microcrystalline; thick to very thick beds with rare, parallel, slightly undulatory, blocky splitting habit, alternating with thin to medium beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; thick/very thick beds are laminated chert-limestones (chert layers 1" to 2" thick, grayish orange (10 YR 7/4),

interbedded with 4" to 8" thick mudstones, has striped appearance); strong petroliferous odor; cliff-former; fissile/laminated intervals less resistant; sharp slightly undulatory contact with unit 33..25

31 FOSSILIFEROUS MUDSTONE: Brownish black (5 YR 2/1), weathers to light gray (N7); microcrystalline; slightly silty; thick beds with minor parallel, planar, slabby splitting habit, alternating with medium beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; sparsely fossiliferous; echinoid ossicles, ostracodes(?), disarticulated small brachiopods and/or pelecypods(?); fossils subparallel to bedding; few small, black (N1) wisps parallel to bedding; strong petroliferous odor; subdued ledge-former; sharp, planar contact with unit 32................................5

30 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; medium beds alternating with medium to thick beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; echinoid ossicles, disarticulated and broken brachiopods and (few) pelecypods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 31..6

29 FOSSILIFEROUS MUDSTONE: Light olive gray (5 Y 6/1), weathers to light gray (N7); microcrystalline; thick beds with rare parallel, planar to slightly undulatory, slabby splitting habit, alternating with medium to thick beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; many echinoid ossicles, many disarticulated and broken brachiopods, few disarticulated pelecypods, few fenestrate bryozoan fragments; fossils randomly oriented and distributed; moderate petroliferous odor; cliff-former; sharp, planar contact with unit 30........................7

28 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; medium to predominantly thick beds with rare, parallel, planar to slightly undulatory, flaggy to slabby splitting habit; sharp, planar to locally slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods and few pelecypods(?), few gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge- to subdued ledge-former; sharp, slightly undulatory contact with unit 29............11

27 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray (N7); microcrystalline; medium to predominantly thick beds with rare parallel, slightly undulatory, slabby splitting habit, alternating with medium and few thick beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; many disarticulated and broken brachiopods, echinoid ossicles, gastropods, few fenestrate(?) bryozoan fragments, ostracodes(?); fossils randomly oriented and distributed; few horizontal to slightly inclined burrows; moderate petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 28....................8

26 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 5/1), weathers to medium light gray (N6); microcrysatlline; medium to thick beds with minor parallel, slightly undulatory, slabby splitting habit, alternating with medium to (few) thick beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; echinoid ossicles and fragments, broken and disarticulated brachiopods, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 27..................7

25 FOSSILIFEROUS WACKESTONE: Light olive gray (5 Y 5/1), weathers to light gray (N7); microcrystalline; thick beds with very minor parallel, planar to slightly undulatory, slabby splitting habit, alternating with medium to thick beds

with parallel, planar, fissile to predominantly laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; many echinoid ossicles, disarticulated and few broken brachiopods and few pelecypods, few fenestrate bryozoan fragments, ostracodes(?), few partial trilobite molds, gastropods; fossils randomly oriented and distributed; local swirled texture (=bioturbation); few burrows(?); moderate petroliferous odor; ledge-former; sharp, planar contact with unit 26........................12

24 SPARSELY FOSSILIFEROUS WACKESTONE: Medium olive gray (5 Y 5/1), weathers to medium light gray (N6); microcrystalline; medium to thick beds with minor parallel, slightly undulatory, slabby splitting habit, alternating with medium to thick beds with parallel, planar to slightly undulatory, fissile to laminated splitting habit; sharp, slightly undulatory to predominantly planar contacts between beds; echinoid ossicles and fragments, disarticulated and few broken brachiopods, few gastropods; most fossils subparallel to bedding, locally randomly oriented, randomly distributed; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 25..................9

23 FOSSILIFEROUS WACKESTONE: Light olive gray (5 Y 6/1), weathers to light gray (N7); microcrystalline; thick beds with very minor, parallel, planar to slightly undulatory, slabby splitting habit, alternating with medium to thick beds with parallel, planar, fissile to predominantly laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; echinoid ossicles and fragments, disarticulated and broken brachiopods and pelecypods, gastropods, ostracodes, disarticulated trilobites, few fenestrate bryozoan fragments; fossils randomly oriented and distributed; swirled texture (=bioturbation); few horizontal burrows; moderate petroliferous odor; cliff-former; sharp, planar contact with unit 24...11

22 SPARSELY FOSSILIFEROUS WACKESTONE: Light olive gray (5 Y 6/1), weathers to light gray (N7); microcrystalline; medium and

thick beds alternating with medium beds with parallel, planar, fissile to laminated splitting habit; sharp, planar contacts between beds; echinoid ossicles, broken and disarticulated brachiopods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 23..................4

21 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; medium to thick beds with rare parallel, slightly undulatory, slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar contacts between beds; sparsely fossiliferous; echinoid ossicles, few disarticulated and broken brachiopods; fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 22...8

20 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light gray; microcrystalline; medium to thick beds with rare parallel, slightly undulatory, slabby splitting habit, alternating with thin beds with parallel, planar, laminated to predominantly fissile splitting habit; sharp, planar contacts between beds; echinoid ossicles, gastropods, few broken and disarticulated brachiopods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 21..................6

19 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; medium to thick beds alternating with medium to (few) thin beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar contacts between beds; echinoid ossicles, disarticulated and few broken brachiopods, ostracodes(?), few gastropods; fossils subparallel to bedding, locally randomly oriented, randomly distributed; strong petroliferous odor; subdued ledge-former; sharp, planar contact with unit 20..................11

18 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; medium beds alternating with thin to (few) medium beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar contacts between beds; few echinoid ossicles and fragments, disarticulated and broken brachiopods; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former; sharp, planar contact with unit 19....................8

17 SPARSELY FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 3/1), weathers to medium light gray (N6) to light gray (N7); microcrystalline; thin to predominantly medium beds with rare parallel, slightly undulatory, flaggy splitting habit, alternating with thin to (few) medium beds with parallel, slightly undulatory, laminated to predominantly fissile splitting habit; sharp, slightly undulatory contacts between beds; predominantly echinoid ossicles, few disarticulated and broken brachiopods, gastropods; fossils randomly oriented and distributed; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 18........................12

16 FOSSILIFEROUS MUDSTONE: Dark olive gray (5 Y 3/1), weathers to light gray (N7); microcrystalline; thin to medium beds, alternating with thin to medium beds with parallel, planar to predominantly slightly undulatory, fissile to laminated splitting habit; sharp, planar to locally slightly undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods, ostracodes(?), few gastropods; fossils subparallel to bedding, locally randomly oriented, randomly distributed; moderate petroliferous odor; subdued ledge-former; sharp, planar contact with unit 17..8

15 SPARSELY FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to medium light gray (N6); microcrystalline; slightly silty; thin to medium beds alternating with medium to predominantly thin beds with parallel, planar to slightly undulatory, laminated to predominantly

fissile splitting habit; sharp, planar contacts between beds; echinoid ossicles, few disarticulated and broken brachiopods; fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former; sharp, planar contact with unit 16...6

14 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light olive gray (5 Y 6/1); microcrystalline; slightly silty; medium to thick beds with minor parallel, slightly undulatory, slabby splitting habit, alternating with thin to medium beds with parallel, planar to slightly undulatory, laminated to predominantly fissile splitting habit; sharp, planar contacts between beds; faint, thin, planar lamina locally visible on weathered surface; few whole and disarticulated brachiopods, echinoid ossicles, gastropods; fossils subparallel to bedding, randomly distributed, stand with slight relief on weathered surface; few chert nodules; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 15.................10

13 SPARSELY FOSSILIFEROUS WACKESTONE: Medium dark gray (N4), weathers to light olive gray (5 Y 6/1); microcrystalline; medium to (few) thin beds with rare parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, laminated to predominantly fissile splitting habit; sharp, slightly undulatory to predominantly planar contacts between beds; echinoid ossicles, few disarticulated and broken brachiopods, ostracodes(?); fossils randomly oriented and distributed; strong petroliferous odor; subdued ledge-former; sharp, planar contact with unit 14..................7

12 FOSSILIFEROUS WACKESTONE: Olive gray (5 Y 4/1), weathers to light olive gray (5 Y 6/1) to pale yellowish brown (10 YR 6/2); microcrystalline; slightly silty; thin to medium beds with rare, parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin beds with parallel, planar to undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory

contacts between beds; thin, planar to slightly undulatory lamina locally visible on weathered surface; many echinoid ossicles, (few) whole and disarticulated brachiopods, gastropods; fossils randomly oriented and distributed, stand with slight relief; several chert nodules and stringers (up to 4" wide, 15' long); few small, dark brownish gray (5 YR 3/1) wisps parallel to bedding; moderate to strong petroliferous odor; subdued ledge-former; sharp, planar contact with unit 13................................16

11 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium to thick beds with minor parallel, slightly undulatory, flaggy splitting habit, alternating with thin to (few) medium beds with parallel, undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; sparsely fossiliferous; disarticulated and broken brachiopods, echinoid ossicles, few gastropods; fossils subparallel to bedding, randomly distributed; strong petroliferous odor; subdued ledge-former; sharp, slightly undulatory contact with unit 12......................7

10 FOSSILIFEROUS WACKESTONE/MUDSTONE: Dark gray (N3), weathers to light gray (N6); microcrystalline; medium to predominantly thick beds (<2' thick) with minor parallel, planar to slightly undulatory, slabby to locally slabby splitting habit, alternating with thin beds with parallel, slighlty undulatory, fissile to predominantly laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; many echinoid ossicles (several broken), disarticulated and broken brachiopods and pelecypods(?), gastropods, bryozoan(?) fragments; fossils randomly oriented and distributed, locally subparallel to bedding; few intermittent less fossiliferous beds (=fossiliferous mudstones); moderate to strong petroliferous odor; ledge-former; sharp, planar contact with unit 11.........................13

9 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to light gray (N7) to pale grayish orange (10 YR 8/4); microcrystalline; medium to thick beds

with minor parallel, planar to slightly undulatory, flaggy to slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; faint, slightly undulatory, thin lamina locally visible on weathered surface; sparsely fossiliferous; echinoid ossicles, disarticulated and broken brachiopods; fossils subparallel to bedding, randomly distributed; scarce chert nodules; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 10.................................5

8 FOSSILIFEROUS WACKESTONE: Dark brownish gray (5 Y 3/1), weathers to medium light gray (N6); microcrystalline; thick to predominantly medium beds with minor parallel, planar to slightly undulatory, flaggy splitting habit, alternating with thin to medium beds with parallel, slightly undulatory, fissile to laminated splitting habit; sharp, planar to slightly undulatory contacts between beds; many echinoid ossicles and fragments, few bryozoan fragments, disarticulated brachiopods, gastropods; fossils parallel to bedding, randomly distributed, slightly less fossilferous than unit 5; moderate petroliferous odor; ledge-former; sharp, planar contact with unit 9..........................9

7 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 4/1), weathers to light gray (N7) to pale grayish orange (10 YR 8/4); microcrystalline; medium to predominantly thick beds with minor parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with thin beds with parallel, undulatory, fissile to laminated splitting habit; sharp, undulatory contacts between beds; echinoid ossicles, gastropods, few whole and disarticulated brachiopods (few broken), disarticulated pelecypods, ostracodes(?); fossils randomly oriented (smaller fossils typically subparallel to parallel to bedding), randomly distributed; few chert nodules and small stringers; moderately fractured; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 8...14

6 FOSSILIFEROUS MUDSTONE: Brownish black (5 YR 2/1), weathers to medium gray (N5); microcrystalline; thick bed with parallel to locally non-parallel, undulatory, fissile to predominantly laminated splitting habit; sparsely fossiliferous; echinoid ossicles, disarticulated brachiopods and pelecypods, ostracodes(?); fossils parallel to bedding, randomly distributed; very strong petroliferous odor; slope-former; sharp, slightly undulatory contact with unit 7......................3

5 FOSSILIFEROUS WACKESTONE: Dark brownish gray (5 YR 3/1), weathers to light gray (N7); microcrystalline; medium to thick beds with minor parallel, slightly undulatory, slabby splitting habit, alternating with thin to medium beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, disarticulated and broken brachiopods (few whole) and pelecypods; fossils randomly oriented and distributed; most fossils subparallel to bedding, randomly oriented; few small chert nodules; moderately fractured; strong petroliferous odor; ledge-former; sharp, planar contact with unit 6......................................5

4 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to light gray (N7); microcrystalline; medium to thick beds with very minor parallel, undulatory, slabby splitting habit, alternating with thin beds with parallel, slightly undulatory to undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; echinoid ossicles, whole and disarticulated brachiopods, few gastropods; most fossils subparallel to bedding, randomly distributed; few chert nodules and small stringers; strong petroliferous odor; ledge-former; planar contact with unit 5............5

3 FOSSILIFEROUS WACKESTONE: Dark brownish gray (5 Y 3/1), weathers to very pale yellowish brown (10 YR 7/2); microcrystalline; thick beds with minor parallel, slightly undulatory, slabby splitting habit, alternating with thin beds with parallel, undulatory, fissile to laminated splitting

habit; sharp, slightly undulatory contacts between beds; many echinoid ossicles and fragments, bryozoan fragments, few whole and many disarticulated and broken brachiopods, gastropods, ostracodes; fossils parallel to bedding, randomly distributed; few small intraclasts(?); moderately fractured; strong petroliferous odor; ledge-former; sharp slightly undulatory contact with unit 4......................6

2 FOSSILIFEROUS MUDSTONE: Olive black (5 Y 2/1), weathers to pale grayish orange (10 YR 8/4); microcrystalline; medium to (few) thick beds with minor parallel, slightly undulatory to undulatory, flaggy to slabby splitting habit, alternating with thin to (few) medium beds with parallel, undulatory, fissile to laminated splitting habit; sharp, slightly undulatory contacts between beds; faint, undulatory, thin lamina visible on weathered surface; sparsely fossiliferous; echinoid ossicles, gastropods, disarticulated and broken brachiopods (few whole) and pelecypods, ostracodes; smaller fossils parallel to bedding, larger fossils randomly oriented, randomly distributed; few small, dark gray (N3) to medium light gray (N6) wisps parallel to bedding; few chert nodules and stringers; extensively fractured; strong petroliferous odor; ledge-former; sharp, slightly undulatory contact with unit 3............11

1 COVER: talus apron at base of cliffs..................unm.

TOTAL: 874.0 feet

VIII. CLOVER MEADOW SECTION

SW 1/4, NE 1/4, section 16, T. 9 S., R. 2 W., Varney quadrangle, USGS 15 minute series. Partial Lombard Limestone section measured along a north-south traverse on two sets of south-facing cliffs separated by a gently sloping hummocky interval. The cliffs are present as slip faces created by large-scale slumping and bedding plane failure in the Lombard Limestone. The lower cliffs (units 1-4) surround an amphitheater filled with very large Lombard Limestone talus blocks. The upper cliffs (units 6-11) are separated from the lower cliffs by a grassy, hummocky slope (unit 5) several hundred feet in width. Slumping and sliding has presumably been facilitated by failure and westward transport along gently westward-dipping bedding planes within the Lombard Limestone and/or at, or near, the Mission Canyon-Lombard Limestone interface.

Hadley (1969) had originally mapped these rocks as Mississippian Mission Canyon Limestone and Mississippian-Pennsylvanian Amsden Formation. Several corals retrieved from these rocks indicate a Chesterian age for these rocks (Sando, personal communication, 1985) and they are here considered of Lombard Limestone affinity. The overlying Amsden Formation, exposed at the top of the upper cliffs, is distinguishable by its red iron-stained color, and poorly to moderately well exposed siltstone, sandstone, and dolomite beds. The base of the red soil and stain maintains a relatively constant stratigraphic position along the upper cliff sequence, although chutes and gullies which traverse this stratigraphic level and pass through the underlying Lombard Limestone are also commonly stained red and/or filled with a reddish soil. The actual base of the Amsden Formation is characterized by a white, discontinuously exposed ledge of dolomite.

Only 183.5 feet of the uppermost part of the Lombard Limestone are exposed at this locality. The amount of actual stratigraphic separation represented by the medial covered interval is unknown, although the hummocky nature of this interval suggests that some recent gravity-induced movement has occurred. The absence of corals and the dissimilarity in bedding habit of unit 6 with respect to unit 4 suggests that the lower cliff sequence is not a down-dropped, repeated exposure of the upper cliff sequence caused by slumping. The upper cliffs are believed to be autochthonous with respect to the Mississippian through Jurassic units exposed to the north on the north limb of a large, west-plunging anticline; the lower cliffs are believed to be allochthonous with respect to this block.

The origin of the Lombard beds exposed in the lower cliffs probably lies just to the east, as transport, via slumping, has been to the west. Westward gravity sliding on non-parallel, intra-Lombard planes of failure may have juxtaposed the two cliff sequences to within 21 stratigraphically vertical feet of each other. The original stratigraphic separation of these beds, or their lateral equivalents, was probably greater than the present 21 feet, so some unknown amount of Lombard section probably is missing. The presence of a post-Jurassic, pre-Quaternary colluvium fault less than 0.9 mile east of the easternmost cliff exposures, and the Recent age of the latest slumping episode which created the cliffy exposures (suggested by the hummocky, cracked ground of the the covered interval) indicate that westward transport was minimal. The Chesterian coral age of the lower cliff sequence, and the conformable(?) or disconformable(?) occurrence of the Amsden at the top of the upper cliff sequence supports a Lombard Limestone classification for these rocks. It seems unlikely, in addition, that the intra-Lombard planes of failure cross-cut bedding at high enough angles to juxtapose two Lombard sequences of initially great vertical separation, given less than one mile to translate. The true separation, obscured by the covered interval, is, therefore, believed to be minimal and this measured section is considered a valid representation of the upper part of the Lombard in the north-central Gravelly Range.

This location can be reached by driving south from Ennis, Montana, along US 287 to the fish hatchery/Varney recreational area turnoff. Turn west off of the highway, cross the Varney bridge, drive approximately 0.4 mile to a left-hand turnoff, and continue due south. Approximately 0.7 miles south of the Kent Ranch, turn west toward the Gerard Ranch. Just before this ranch, turn south onto Forest Route 292. Continue south-southwest to the crest of the Gravelly Range. At the junction with Forest Route 290, turn south. The Clover Meadows area is located approximately two miles southeast of the junction of FR 290 and FR 163 (Warm Springs Road). Hike approximately 0.4 mile west of FR 290 to the cliff exposures.

Unit	Lithology	Ft.
11	DOLOMITE: White (N9); saccharoidal (moderately crystalline); thick to very thick beds; massive; laterally discontinuous ledge-former; moderately well exposed; basal(?) Amsden Formation.............	unm.
10	FOSSILIFEROUS MUDSTONE: Very light olive (5 Y 7/1), weathers to light gray (N8) to white (N9); microcrystalline; thin, planar to slightly undulatory beds with parallel, slightly undulatory, laminated splitting habit; few echinoid ossicles, broken pelecypods, ostracodes; fossils randomly oriented and distributed; small, ovoid, white clay-filled pockets common; no petroliferous odor; slope-former; poorly exposed; upper and lower contact obscurred; thin ledge crops out one foot below, and is parallel to, unit 11 ledge..........................	18
9	FOSSILIFEROUS WACKESTONE: Very pale yellowish brown (10 YR 7/2), weathers to light gray to grayish blue (5 PB 5/2); microcrystalline; medium to thick beds with minor parallel, planar to undulatory, laminated to flaggy splitting habit; most beds lacking internal splitting habit; echinoid ossicles, disarticulated and (many) broken pelecypods, broken brachiopods, indeterminate coral fragments, ostracodes; much finely comminuted fossil debris; fossils randomly oriented and distributed; very weak petroliferous odor; ledge-former......................................	46
8	DOLOMITIC MUDSTONE: Yellowish gray (5 Y 7/2), weathers to yellowish gray (5 Y 8/1) to light olive gray (5 Y 6/1); microcrystalline to finely saccharoidal; silty; thick bed; non-fossiliferous; scattered, small black (carbonaceous?) wisps common; very weak petroliferous odor; basal contact covered; thin bed with parallel, undulatory, fissile to laminated habit overlies thick bed with sharp, slightly undulatory contact; sharp, undulatory contact between thin bed and unit 9..	2.5
7	FOSSILIFEROUS MUDSTONE: Moderate yellowish brown (10 YR 5/4), weathers to pale grayish orange (10 YR 8/4) to pale grayish blue	

(5 PB 6/2); microcrystalline; dolomitic; thin to medium, planar beds with minor parallel, planar to slightly undulatory, flaggy splitting habit; echinoid ossicles, disarticulated and broken brachiopods and pelecypods, trilobite fragments, ostracodes; fossils randomly oriented and distributed, but weak shape fabric locally; very subdued ledge-former to slope-former; poorly exposed.................................22

6 FOSSILIFEROUS WACKESTONE: Pale yellowish brown (10 YR 6/2), weathers to moderate yellowish brown (10 YR 5/4) to pale red (10 R 6/2); microcrystalline; medium to thick, planar beds with local, minor, parallel, planar to slightly undulatory, slabby to blocky splitting habit; disarticulated and broken brachiopods (including indeterminate Productids), echinoid ossicles (including Pentacrinus) and partial stems, fenestrate and indeterminate ramose bryozoan fragments, disarticulated trilobites, ostracodes; fossils randomly oriented and distributed, stand with slight relief on weathered surface; small, local manganese dendrites on weathered surface; horizontal burrows; weak to moderate petroliferous odor; ledge-former......................................12

5 COVER: Grassy; hummocky; moderate brown (5 YR 4/4) to moderate reddish brown (10 YR 4/6) soil; scarce fossiliferous wackestone float.................................21

4 FOSSILIFEROUS WACKESTONE: Dark yellowish brown (10 YR 4/2), weathers to pale yellowish brown (10 YR 5/4) to grayish orange (10 YR 7/4); microcrystalline; thick to very thick beds, with locally pronounced parallel, planar to slightly undulatory, slabby to blocky splitting habit; many echinoid ossicles and fragments, disarticulated and broken brachiopods, fenestrate and indeterminate ramose bryozoan fragments, corals (including *Siphonophyllia* sp.), partial trilobite molds, ostracodes; fossils randomly oriented and distributed, stand with slight to moderate relief on weathered surface; corals chiefly occur in upper 10' of unit, most randomly distributed, few clustered; few chert

nodules and stringers; strong to very strong petroliferous odor; cliff-former............24

3 SPARSELY FOSSILIFEROUS WACKESTONE: Dark yellowish brown (10 YR 4/2), weathers to yellowish gray (5 Y 7/2); microcrystalline; thick, planar beds with parallel, undulatory, laminated to flaggy splitting habit; echinoid ossicles, disarticulated and broken brachiopods, fenestrate fronds and indeterminate bryozoan fragments, ostracodes; fossils randomly oriented and distributed; many horizontal burrows; moderate petroliferous odor; sharp, slightly undulatory upper and lower contacts with units 4 and 2........................3

2 FOSSILIFEROUS PACKSTONE: Very light olive gray (5 Y 7/1), weathers to light gray (N7); microcrystalline; medium to thick, planar beds with absent to minor parallel, planar to slightly undulatory, flaggy to slabby splittng habit; few, very thin to thin interbeds with parallel, planar to undulatory, laminated to locally fissile splitting habit; echinoid ossicles (including Pentacrinus) and fragments, few whole and many disarticulated and broken brachiopods, corals (including _Siphonophyllia_ sp.), gastropods, indeterminate bryozoan fragments; most fossils parallel to bedding, randomly distributed, stand with slight relief of weathered surface; corals concentrated within 2' interval (18' to 20' up section), scarce throughout remainder of unit; horizontal burrows; many chert nodules (up to 8" diameter) and stringers (up to 25' long and 4"-5" in diameter); weak petroliferous odor; cliff-former..............23

1 COVER: Fossiliferous wackestone and packstone float (some with corals, including _Amplexizaphrentis_ large sp.); many very large talus blocks; light gray (N7) to very light gray (N8); talus field at base of cliffs...unk.

TOTAL: 183.5 feet

IX. SHEEP CREEK CANYON SECTION

North side of Sheep Creek Canyon, N 1/2, NE 1/4, NW 1/4, section 18, T. 9 S., R. 8 W., Gallagher Mountain quadrangle, U.S.G.S. 7.5 minute series. Kibbey Formation section measured from west to east, beginning at uppermost limestone ledge of Mission Canyon cliff sequence. The section is measured along a N 40 E traverse, approximately 400 feet north-northwest of the dirt road along Sheep Creek. The Kibbey is very poorly exposed here as isolated, vertical, very low relief outcrops separated by soil-covered intervals of variable thickness.

This location can be reached by travelling approximately 8.5 miles south from Dillon along Blacktail Deer Creek Road to the Matador Cattle Ranch (section 32, T. 8 S., R. 8 W.; Rock Island Ranch on county map). Continue approximately 1.8 miles to a dirt road which turns northwest toward the Blacktail Mountains. Follow this road to the fenceline and gate at the mouth of Sheep Creek Canyon; park here. Hike west along the dirt road for approximately one-quarter mile. At this point the canyon abruptly widens, coincident with the Mission Canyon-Kibbey contact. The Kibbey is represented by the gently sloping section between the Mission Canyon cliffs to the east and the moderate to steep slopes, underlain by the Lombard Limestone, to the immediate west. The land west of the fenceline along the east entrance of the canyon is privately owned, but permission to enter this area can be obtained by writing to Don Connover (c/o Connover Ranch, Dillon, Montana).

Unit	Lithology	ft.
15	SPARSELY FOSSILIFEROUS WACKESTONE: Dark yellowish brown (10 YR 4/2), weathers to pale grayish orange (10 YR 8/4) to medium light gray (N6); microcrystalline; thin- to medium-bedded; echinoid ossicles, disarticulated brachiopods, ostracodes(?); fossils randomly oriented and distributed; weak petroliferous odor; ledge-former; base of Lombard Limestone..................................	unm.
14	COVER: Grayish orange (10 YR 7/4) to moderate yellowish brown (10 YR 5/4) soil and scarce limy siltstone to fine-grained sandstone float...	25
13	QUARTZ ARENITE: Moderate yellowish brown (10 YR 5/4), weathers to very pale yellowish brown (10 YR 7/2); very thin, slightly undulatory laminations of medium sand and very fine sand; subrounded to rounded quartz grains; very thin, slightly undulatory beds; calcareous cement; non-fossiliferous; very subdued ledge-former..	1.5
12	COVER: Grayish orange (10 YR 7/4) to moderate yellowish brown (10 YR 5/4) soil; scattered, scarce, silty to sandy dolostone and quartz arenite float....................................	17
11	QUARTZ ARENITE: Dark yellowish orange (10 YR 6/6), weathers to grayish orange (10 YR 7/4); fine-grained; subangular to subrounded quartz grains; no discernable bedding; massive; mottled; dolomite-cemented; non-fossiliferous; slightly friable; very subdued ledge-former..................	5
10	COVER: Moderate yellowish brown (10 YR 5/4) soil...	4
9	DOLOMITIC QUARTZ ARENITE: Pale reddish brown (10 R 5/4), weathers to pale red (10 R 6/2); fine-grained; subangular to subrounded quartz grains; mottled; burrows and root traces(?); dolomitic; non-fossiliferous; friable; very subdued ledge-former.......................................	2
8	COVER: Grayish orange (10 YR 7/4) to pale yellowish orange (10 YR 7/2) soil; isolated dolomitic(?) to moderately limy,	

very fine-grained quartz sandstone and
siltstone float....................................39

7 SANDY DOLOSTONE: Pale yellowish brown
(10 YR 6/2), weathers to very pale orange
(10 YR 8/2); very finely crystalline;
scarce subrounded, very fine-grained
quartz grains; extensivey mottled; many
clay scallops and wisps; non-fossiliferous;
dense; very subdued ledge-former....................2

6 COVER: Dark yellowish orange (10 YR 6/6)
soil...10.5

5 SILTY DOLOSTONE: Dark yellowish orange
(10 YR 6/6), weathers to grayish orange
(10 YR 7/4); very finely crystalline;
slightly silty; mottled/patchy; dense;
non-fossiliferous; very subdued
ledge-former.......................................2

4 COVER: Dark yellowish orange (10 YR 6/6)
soil...4

3 SILTY DOLOSTONE: Dark yellowish orange
(10 YR 6/6), weathers to pale grayish
orange (10 YR 8/4); very finely
crystalline; slightly silty; mottled;
dense; non-fossiliferous; very subdued
ledge-former.......................................1

2 COVER: Moderate yellowish brown (10 YR 5/4)
soil...5

1 MUDSTONE: Medium gray (N5), weathers to light
gray (N7); finely crystalline limestone;
slightly brecciated; cliff- and
ledge-former; top of Mission Canyon
Limestone; uppermost ledge is discontinuous,
with Kibbey soil filling gaps along strike
(= undulatory contact? on Mission Canyon
Limestone)......................................unm.

TOTAL: 118.5 feet

APPENDIX B: SOURCES FOR KIBBEY FORMATION AND LOMBARD LIMESTONE ISOPACH DATA

Section		Source
1.	Snowslide Mountain	Witkind, 1964
2.	Red Rock Lakes area	Witkind, 1976
3.	Red Rock River	This report
4.	Clover Divide	This report
5.	Sawtooth Mountain	This report
6.	Sunset Peak	This report
7.	Hogback Mountain	This report
8.	Sliderock Mountain	This report
9.	Snowcrest Mountain	This report
10.	Clover Meadows	This report
11.	Horse Prairie area	W. J. Goodhue, in prep., communication, 1985
12.	Armstead anticline area	Hildreth, 1980
13.	Sheep Creek Canyon	This report
14.	Baldy Mountain	Hadley et al., 1980
15.	Station 166 (Gravelly Range)	Hadley et al., 1980
16.	Station 170 (Gravelly Range)	Hadley et al., 1980
17.	Wigwam Creek (Gravelly Range)	Hadley et al., 1980
18.	Greenhorn Mountain area	Sharp, 1969
19.	Big Dry Creek	Tysdal, 1970
20.	Locality 1	Brewster, 1984
21.	Locality 2	Brewster, 1984
22.	Locality 3	Brewster, 1984
23.	Locality 4	Brewster, 1984
24.	Locality 5	Brewster, 1984
25.	Middle Fork Sixteenmile Canyon	Guthrie, 1984
26.	Horse Mountain	Guthrie, 1984
27.	North Angler Lake	Guthrie, 1984
28.	Bighorn Lake	Guthrie, 1984
29.	Southeast Sacajawea	Guthrie, 1984
30.	Ross Peak	Guthrie, 1984
31.	Maynard Creek	Guthrie, 1984
32.	Bridger Peak	Guthrie, 1984
33.	Bridger Canyon	Guthrie, 1984
34.	Rocky Canyon	Guthrie, 1984
35.	Elkhorn Mountains	Klepper et al., 1957
36.	Lombard Station	Wardlaw and Pecora, 1985
37.	Bell Canyon	Wardlaw and Pecora, 1985
38.	Railroad Canyon	Wardlaw and Pecora, 1985
39.	Townsend	Harris, 1972
40.	Jefferson Canyon	Harris, 1972
41.	Logan	Harris, 1972
42.	Toston	Harris, 1972
43.	Ashbough Canyon	Pecora, 1981

APPENDIX C

COLLECTION LOCATIONS OF SURFACE SAMPLES FOR GEOCHEMICAL ANALYSES (PETROLEUM SOURCE ROCK POTENTIAL)

Map location	Section name	Map Coordinates	Sample number	Lombard Ls. lithofacies
I	Red Rock River	SW 1/4, NW 1/4, section 28, T. 13 S., R. 7 W.	1	Lime mudst.
			2	Lime mudst.
			3	Lime mudst
			4	Lime mudst.
II	Clover Divide	NW 1/4, SE 1/4, and SE 1/4, NW 1/4, section 23, T. 12 S., R. 6 W.	5	Lime mudst.
			6	Lime mudst.
			7	Lime mudst.
			8	Lime mudst.
			9	Lime mudst.
			10	Lime mudst.
III	Sawtooth Mountain	NW 1/4, SE 1/4, section 8, T. 12 S. R. 5 W.	11	Calc. shale
IV	Sunset Peak	NW 1/4, SE 1/4, section 24, T. 11 S., R. 5 W.	12	Fossilif. wacke-pack.
V	Hogback Mountain	SE 1/4, section 6, T. 11 S., R. 4 W.	13	Lime mudst.
			14	Lime mudst.
			15	Calc. shale
			16	Calc. shale
VI	Sliderock Mountain I	SW 1/4, NW 1/4, section 24 T. 10 S., R. 4 W.	17	Lime mudst.
			18	Lime mudst.
			19	Lime mudst.
VII	Snowcrest Mountain	SE 1/4, NE 1/4, section 1, and SW 1/4, NW 1/4, section 6, T. 10 S., R. 3 W.	20	Lime mudst.
			21	Lime mudst.
			22	Lime mudst.

NOTE:
1) Roman numerals under map location heading correspond to Figure 54.
2) Sample numbers correspond to those on tables 3 and 4.

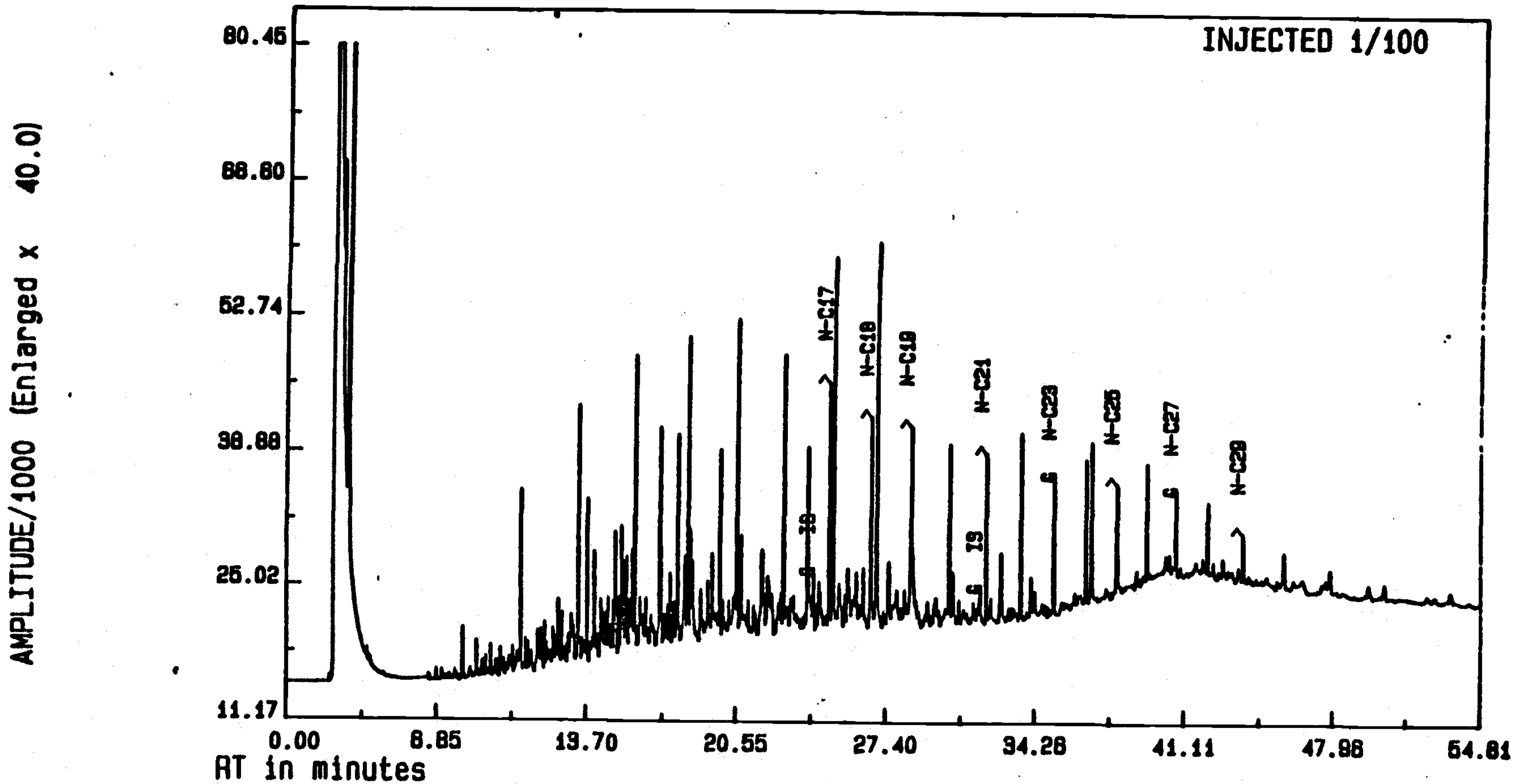
APPENDIX D

GAS CHROMATOGRAPHY RESULTS

Twenty-two Lombard Limestone surface samples collected in the Snowcrest Range were analyzed for petroleum source rock potential. Gas chromatography analyses were completed on the six samples which yielded the most promising potential source rock values; these chromatograms are arranged by sample number, as listed below (see Appendix C for Township and Range coordinates of sample locations).

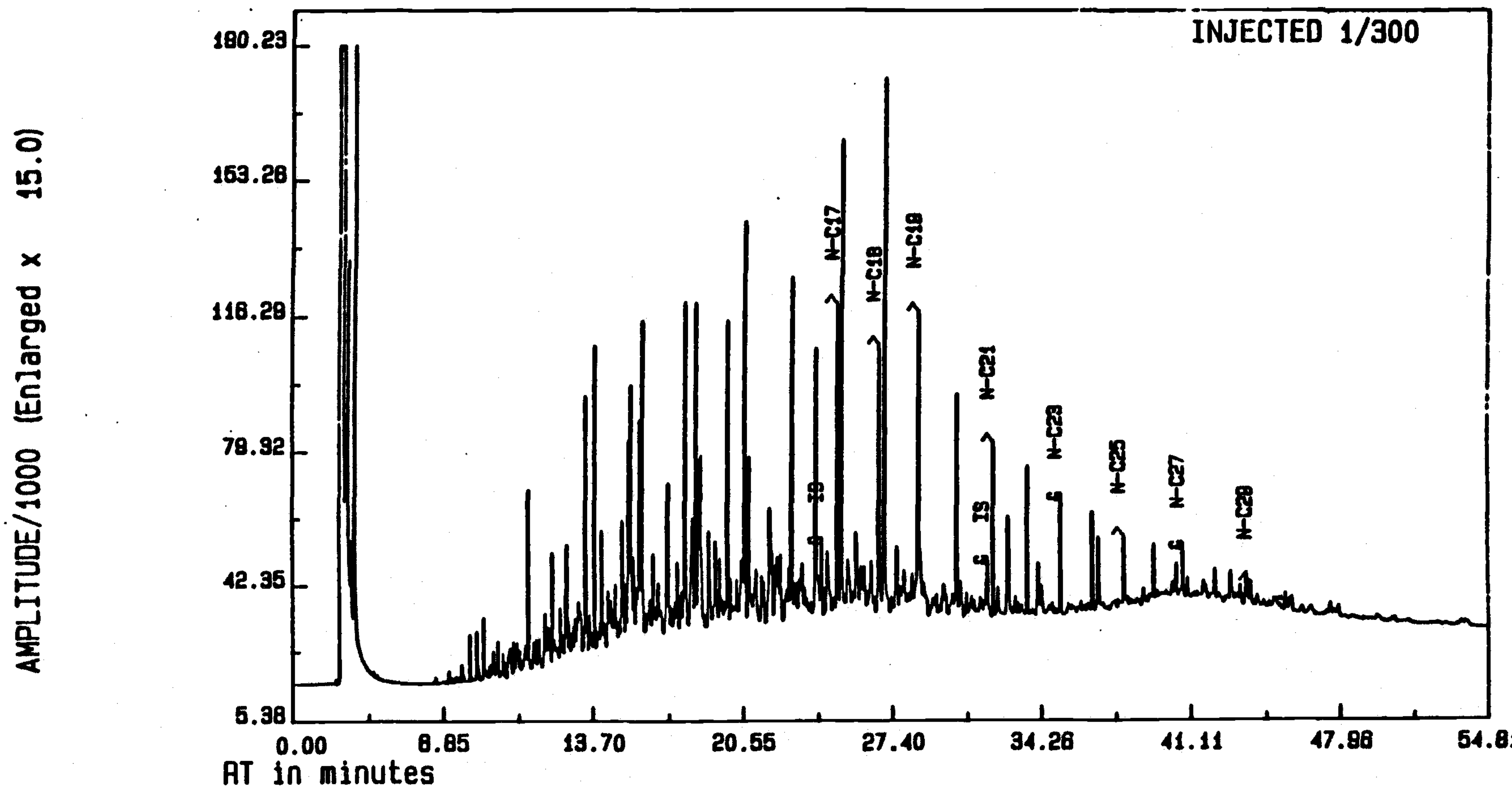
Sample	Lithofacies	Collection site
10	Lime mudstone	Clover Divide
11	Calcareous shale	Sawtooth Mountain
12	Fossil. wacke-pack.	Sunset Peak
14	Lime mudstone	Hogback Mountain
15	Calcareous shale	Hogback Mountain
16	Calcareous shale	Hogback Mountain

Sample 10 / Lime mudstone / Clover Divide



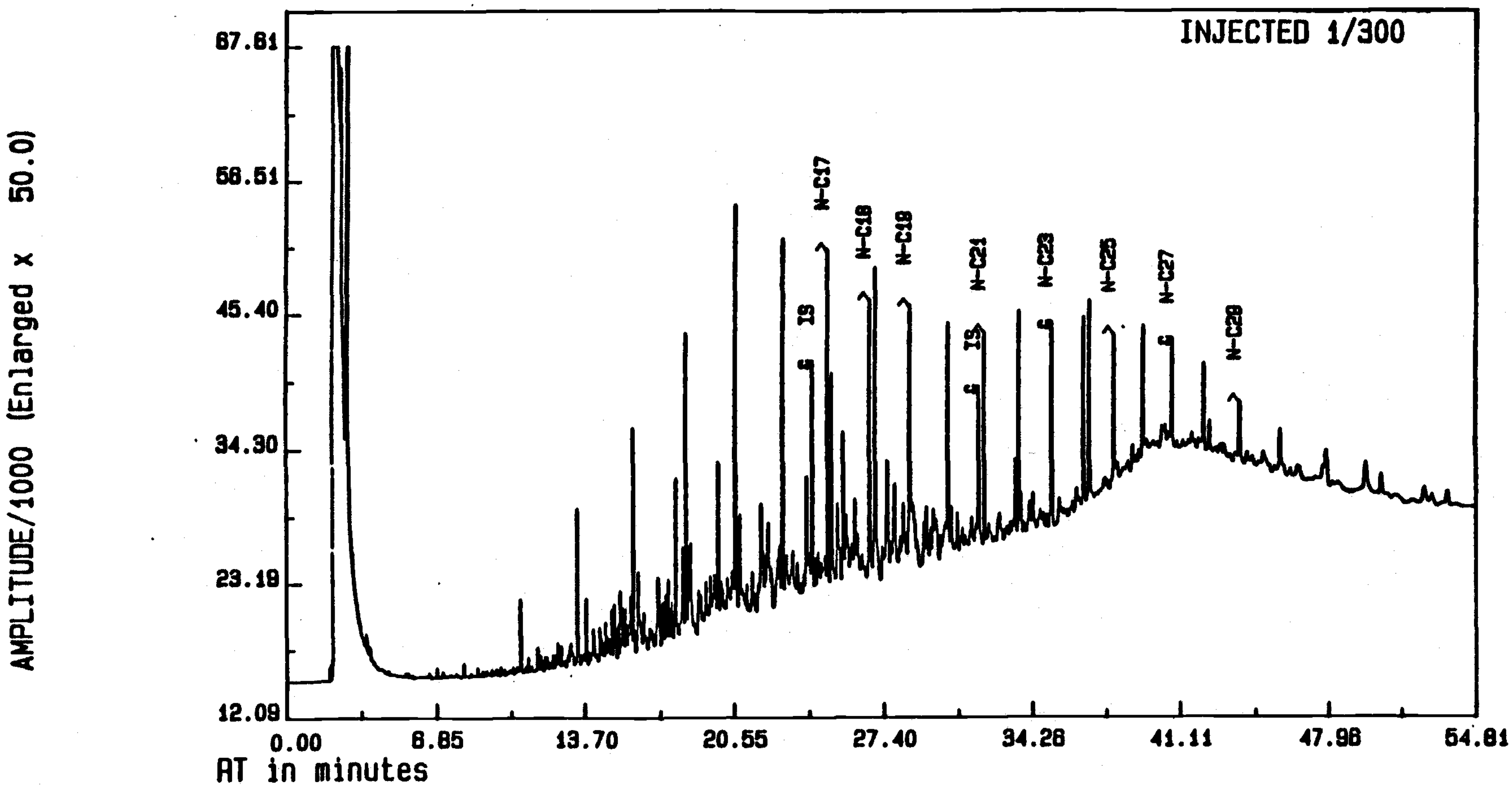
SAMPLE: DJB MONTANA INJECTED AT 18:25:31 ON FEB 13, 1985
Meth: HMW09 Raw: RT9664 Proc: PA7

Sample 11 / Calcareous shale / Sawtooth Mountain



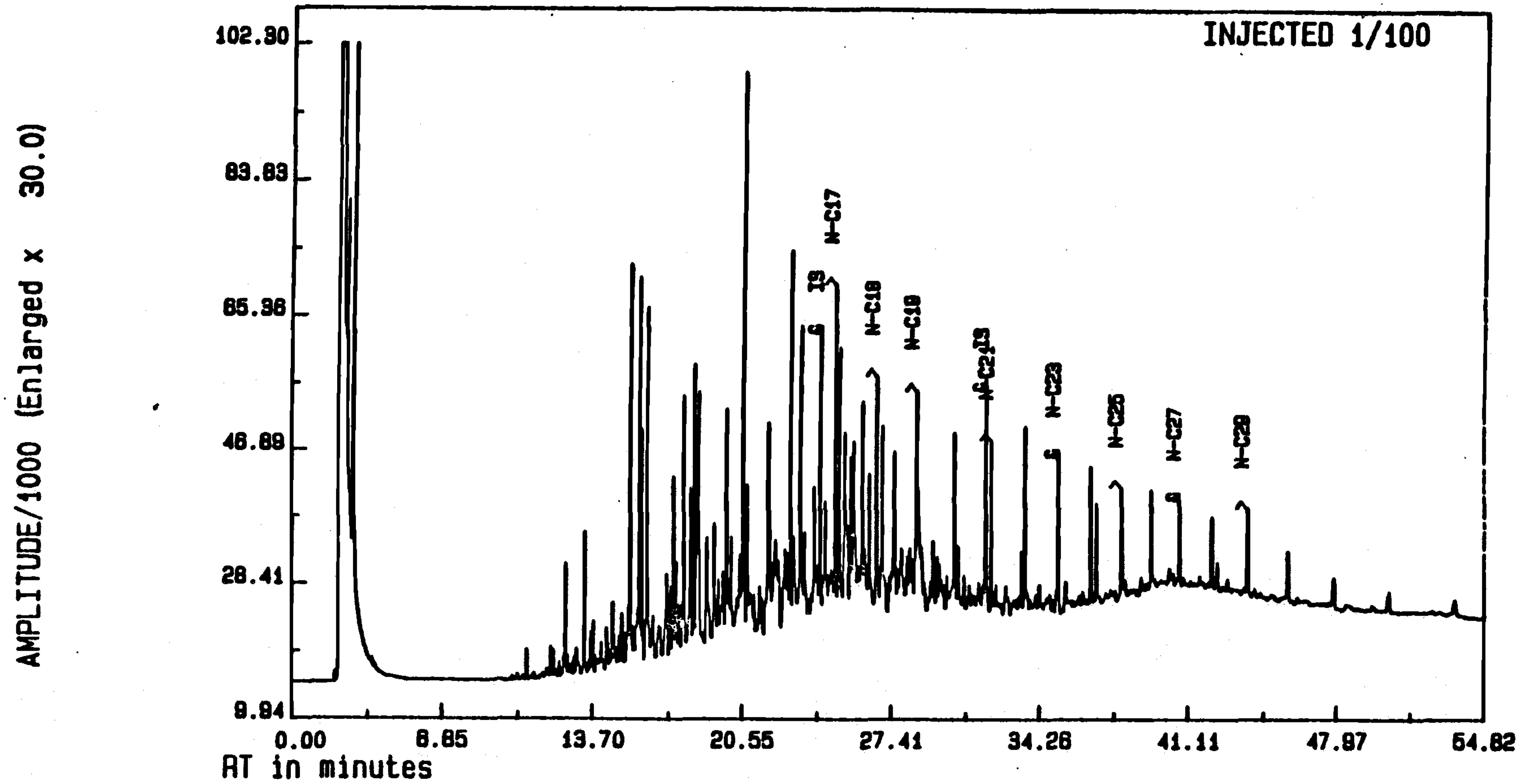
SAMPLE: DJB MONTANA INJECTED AT 11:17:32 ON FEB 13, 1985
Meth: HMW09 Raw: RT9662 Proc: PR1

Sample 12 / Fossiliferous wackestone-packstone / Sunset Peak



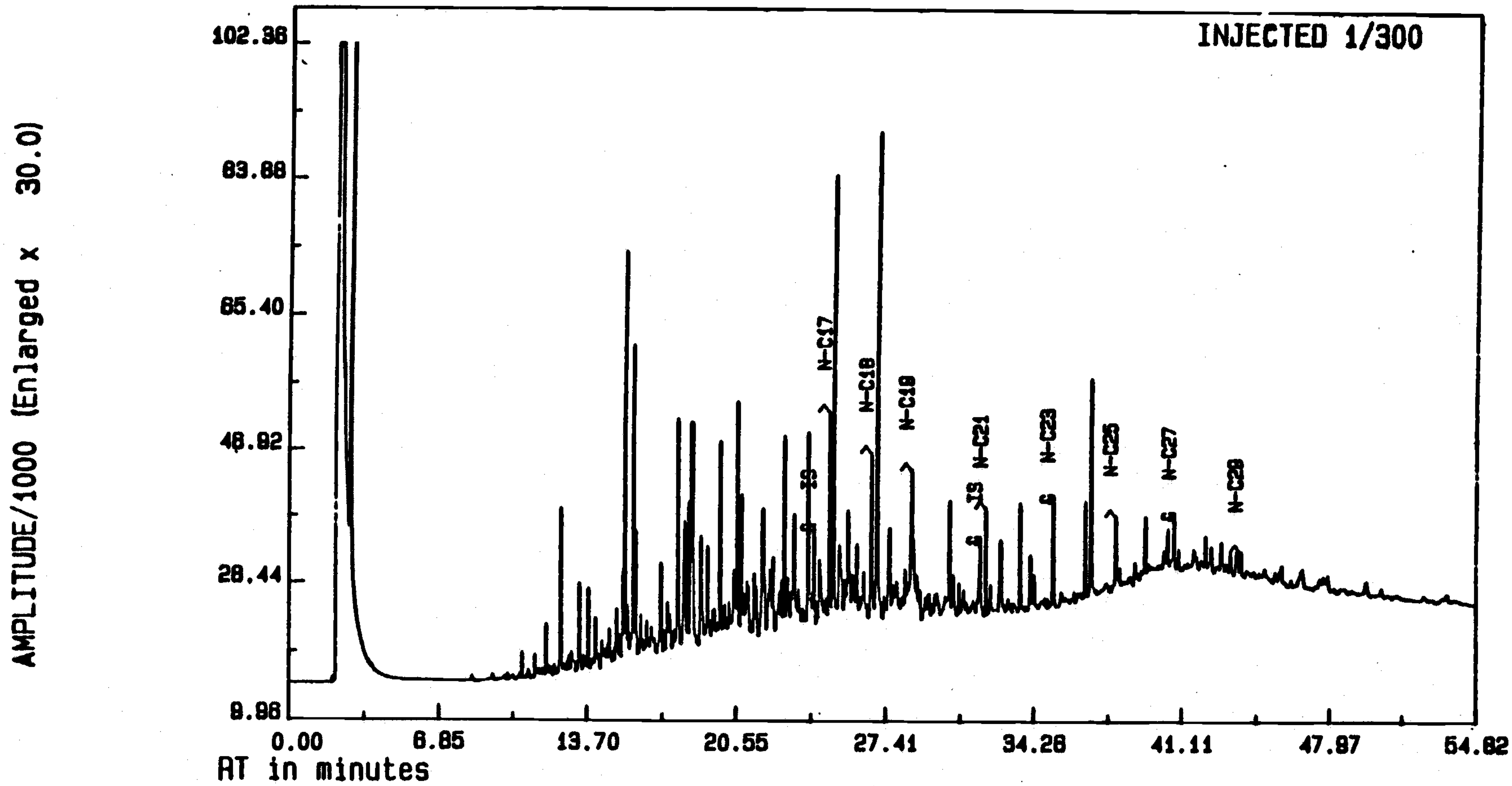
SAMPLE: DJB MONTANA INJECTED AT 12: 28: 49 ON FEB 13, 1985
Meth: HMW09 Raw: RT9668 Proc: PR2

Sample 14 / Lime mudstone / Hogback mountain



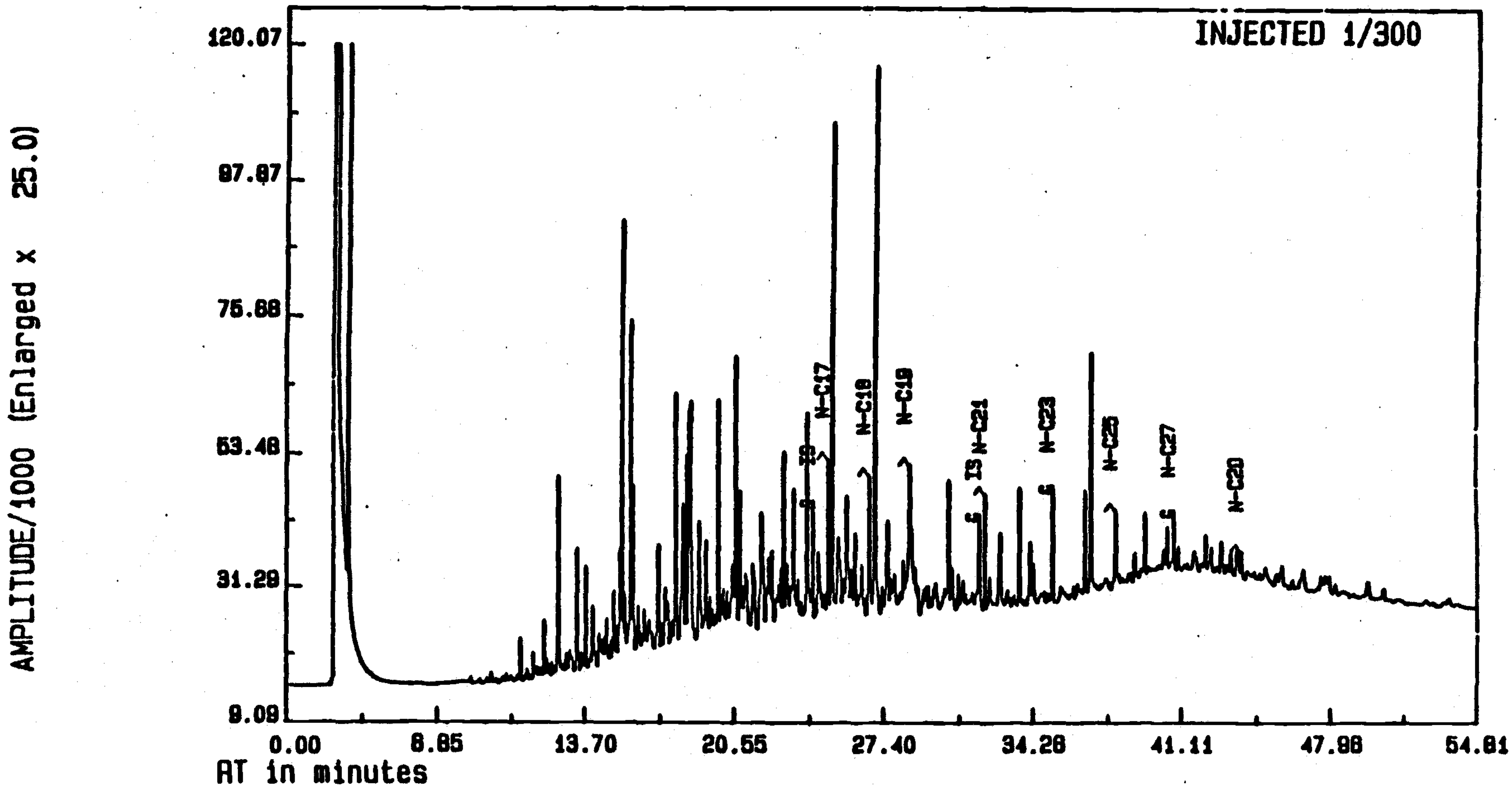
SAMPLE: DJB MONTANA INJECTED AT 17:14:08 ON FEB 13, 1985
Meth: HMW09 Raw: RT9665 Proc: PA6

Sample 15 / Calcareous shale / Hogback Mountain



SAMPLE: DJB MONTANA INJECTED AT 14:51:26 ON FEB 13, 1985
Meth: HMW09 Raw: RT9668 Proc: PR4

Sample 16 / Calcareous shale / Hogback Mountain



SAMPLE: DJB MONTANA INJECTED AT 13:40:07 ON FEB 13, 1985
Meth: HMW09 Raw: RT9667 Proc: PR3