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Paleogeography and Paleoenvironments of the Lower Unit, Fossil Butte Member, Eocene Green River Formation, Southwestern Wyoming

Roberto Enrique Biaggi

ABSTRACT

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During Eocene time sediment accumulated in Fossil Lake, in what developed to be a small linear and structurally controlled basin. Fossil Lake was one of several lakes into which the Green River Formation was deposited in Wyoming, Utah and Colorado.

Detailed stratigraphic analysis of the Lower Unit of the Fossil Butte Member revealed a well developed lacustrine sequence south of Fossil Butte, and indicates four major depositional facies: (1) open lacustrine, (2) marginal lacustrine, (3) carbonate mudflat, and (4) marginal fluvio-deltaic. The open lacustrine facies is characterized by kerogen rich to kerogen poor finely laminated micrites , that consist mainly of calcite and very little dolomite. These carbonates contain well preserved fossil fish, ostracodes, molluscs and the kerogen that was produced mainly by algae. These rocks grade towards the margins into micrites that become more bioturbated closer to the margin of the lake, as well as into ostracodal and gastropodal limestones. Nearshore carbonates consist mostly of calcite and usually are well bioturbated. Typical fossils include molluscs and ostracodes. In some localized areas limestones can become oolitic, contain some typical nearshore plant remains and even some rare beach lag deposits of vertebrate bones. The carbonate mudflat facies is mainly restricted to the eastern margin where sediments were subaerially exposed

and conditions favored precipitation of dolomite as indicated by several units with mudcracks. Sudden transgressions of the lake produced higher energy conditions which resulted in carbonate being ripped-up on the mudflat and subsequently deposited over scoured surfaces. Although fluvial events occurred through the life of the lake, towards the end of Lower Unit time fluvial activity increased. A Gilbert-type delta developed from the southwest prograding into the lake and virtually filling the whole lake, culminating Lower Unit time. Deltaic sediments consist of siliciclastic sandstones, siltstones and mudstones. Deltaic foresets characterize these sandstones, and fossil reptiles, mammals, fish, molluscs and ostracodes also occur.

The lateral and vertical relationship of Lower Unit lithofacies reflect the dynamic nature of Fossil Lake, where the interplay of a combination of factors such as distance from depocenter to margin, changes in depth, oxygenation, siliciclastic and carbonate sediment influx, and productivity resulted in a typical lithofacies succession from basin depocenter to margin: kerogen rich laminated micrites to kerogen poor laminated micrite to micrites and limestones to mudstones, siltstones and sandstones. This relationship also occurs vertically, but sudden variations of diverse factors resulted in cycles of two or more of these lithofacies, as well as abrupt changes in lithofacies deposition.

This study has further documented the importance of fluvial influences on the distribution of kerogen and the deposition of facies sequences within ancient lake complexes. It has provided a detailed and unique insight into fluvial-lacustrine transitions and relationships, only seen in core in other Green River Formation basins.

Clear Creek, at the depocenter of Fossil Lake during Lower Unit time, contains the best developed lacustrine sequence of the Lower Unit, Fossil Butte Member, Green River Formation, southwestern Wyoming.

LOMA LINDA UNIVERSITY

Graduate School

PALEOGEOGRAPHY AND PALEOENVIRONMENTS OF THE LOWER UNIT, FOSSIL BUTTE MEMBER, EOCENE GREEN RIVER FORMATION, SOUTHWESTERN WYOMING

by

Roberto E. Biaggi

A Thesis in Partial Fulfillment
of the Requirements for the Degree Master of Science
in Geology

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Each person whose signature appears below certifies that this thesis in his opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABBREVIATIONS

Study Localities

AR: Angelo Ranch
BD: Bear Divide
CaC: Carter Creek
CC: Clear Creek
ChC: Chicken Creek
FB: Fossil Butte
FR: Fossil Ridge
HC: Hill Creek
LMC: Little Muddy Creek
ShC: Sheep Creek
S/LMC: Sheep Creek/Little Muddy Creek

Lithofacies

KRLM:	Kerogen rich laminated micrite (oil shale)
KPLM:	Kerogen poor laminated micrite
KPLMSil	Kerogen poor laminated micrite with siliciclastics
Mic:	Micrite
LS:	Limestone
MS:	Mudstone
Slst:	Siltstone
SS:	Sandstone

Lithologic Subunits of the Lower Unit

SS: Sandstone subunit
ULS: Upper Limestone subunit
LWM: Lower White Marker subunit
LSH: Lower Shale subunit

INTRODUCTION

General Statement and Significance

Ever since the first discovered and best known of the great Tertiary lake basins of the West, the Green River Basin, became famous because of it's abundant fossil remains, geologists and paleontologists have been interested in the rich oil shales and fossil fish typical of these widespread Eocene lake deposits. The Green River Formation of southwestern Wyoming, northwestern Colorado, and northeastern Utah was deposited in a system of four lakes which existed in intermontane basins during the Early and Middle Eocene (Bradley 1963). Lacustrine sedimentation in this region began in the Paleocene with Lake Flagstaff in Utah. In the Eocene, lacustrine sediments were deposited in four lakes: Lake Gosiute, Lake Uinta, Fossil Lake and in Piceance Creek basin (Figure 1). Fossil Lake, the smallest, and adjacent to the much larger Lake Gosiute, occupied the Fossil Syncline, now called Fossil Basin. Fossil Butte National Monument is near the geographical center of Fossil Basin.

In this study the sediments and fossils of the Lower Unit (informal term coined by Buchheim and Eugster, 1989, in preparation) of the Fossil Butte Member of the Green River Formation were studied with the primary objective of reconstructing the paleogeography and paleoenvironments of a sedimentary basin that records a complete sequence of lacustrine facies and contains an abundant fossil fauna and flora.

A basin analysis study of the Lower Unit is significant because: 1. The Lower Unit is probably the least studied and less understood of the Fossil Butte Member units. It is considerably different from other lacustrine deposits. Its extent and total thickness was not known until this study. In a concentrated 600 sq. mile area (vs a 10,000 sq. mile area in similar Green River Formation basins) the entire depositional basin is found. This allowed

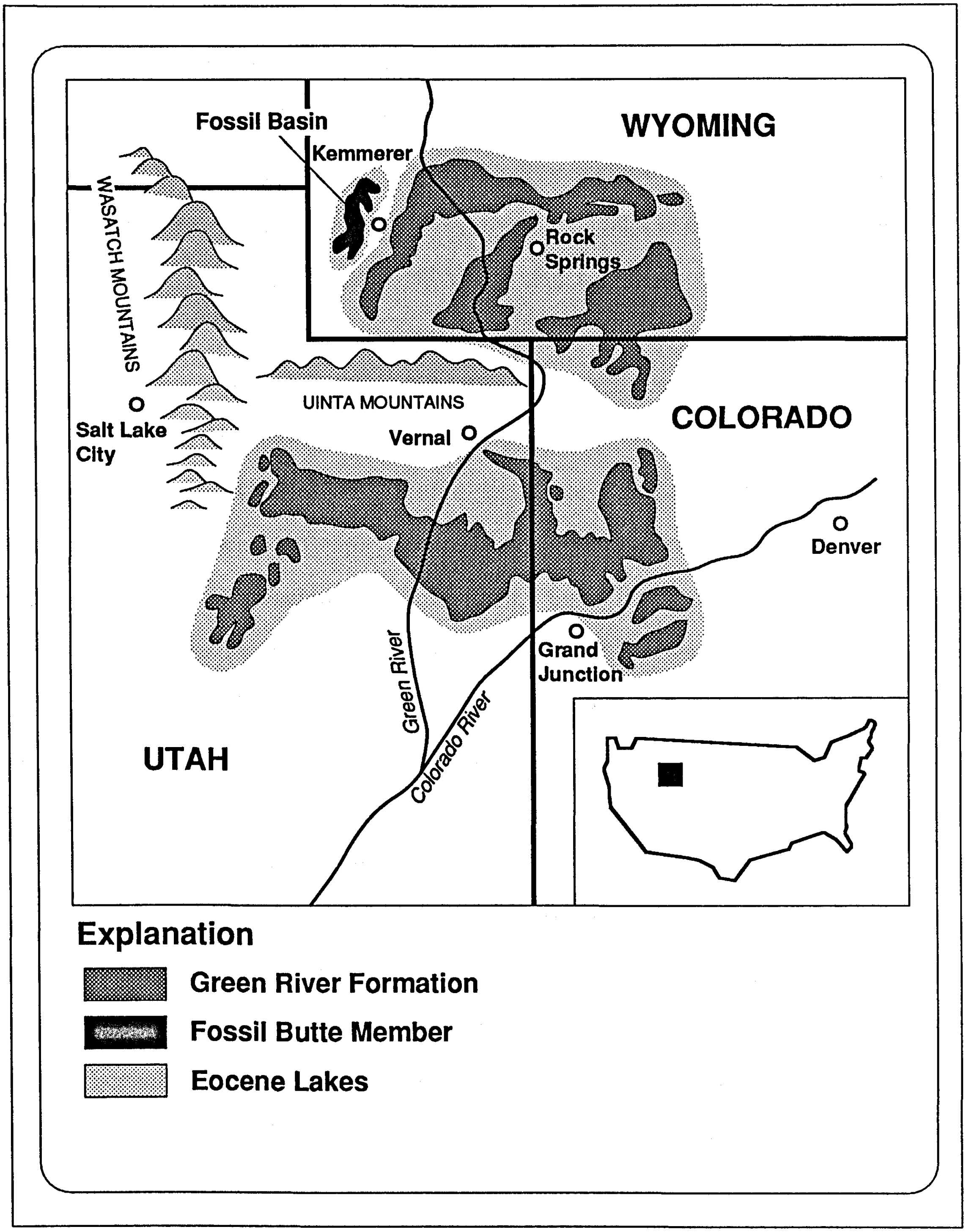


Figure 1. Map showing the location of Fossil Basin in southwestern Wyoming and the location of other Eocene lakes in Wyoming, Utah and Colorado. Sediments of the Green River Formation were deposited in these lakes.

a detailed basin study in a short period of time, as well as provided insights into facies and paleoecology changes not observable elsewhere.

Not only is it in a "concentrated" basin, but the lower Unit is a unique sequence of interbedded fluvial, lacustrine, and fluvial-lacustrine rocks and appears to record the most complete sequence of lacustrine facies that the investigator is aware of. Both lacustrine carbonates containing abundant fossil fishes and fluvial sandstones are interbedded indicating extreme and dynamic depositional changes. An understanding of these relationships may explain the faunal changes as well as the occurrence of various species of fish at different stratigraphic horizons (paleoecology).

The Lower Unit is ideal for a complete basin analysis study including reconstruction of paleogeography, depositional environments, and paleoecology of a sedimentary basin. Formation exposures are excellent, making possible a complete cross-sectional reconstruction of the basin in both a north-south and west-east direction.

Mass mortalities of juvenile *Diplomystus* (herring; about $300/m^2$) in at least one of the lacustrine carbonate interbeds are not known from any other locality. The relationship of this unit to both vertical and lateral lithologic changes may help explain this occurrence. The reason for such mass mortalities are not well understood.

A study of the wide variety of subenvironments in the Lower Unit, from fluvial plain, deltaic, littoral, and open-water will shed light on the depositional processes and paleoecology operating in ancient lake environments.

Because this study will involve a study of varied lithologies present in the Lower Unit such as dolomite, oil shale, and laminated carbonates, it may shed significant light on the origin of these rock types. The origin of dolomite, oil shale, and laminated micrite are unresolved problems and still subject to debate and controversy (Boyer 1982).

Petroleum Potential: large oil fields are developed in transitional fluvio-lacustrine facies in the Uinta Basin, but these facies and their relationships are only known from core and well log data. The similar situation, but well exposed in outcrops in Fossil Basin will further our understanding of this relationship.

PREVIOUS WORK

Early work in Fossil Basin, Wyoming was motivated by the discovery of an abundant and well preserved fossil fish fauna in the neighboring Green River Basin. The existence of fossils (invertebrates) in the Green River Formation was documented in early reports in diaries and journals of missionaries such as S.A.Parker in 1840 and explorers like J.C.Freemont in 1845 (Grande 1980).

The first fossil obtained and described from what now is the Green River Formation was a small herring (3.5 in) found by Dr. John E. Evans at the famous Petrified Fish Cut (located on the main line of the Union Pacific Railroad about 2 mi W of Green River, Wyoming), and described by Leidy in 1856 under the name of *Clupea humilis* (Leidy 1872). Under the auspices of the U. S. Department of the Interior, Geological and Geographical Survey of the Territories, Hayden conducted from 1867-1878 most of the first geological and paleontological studies in the area, resulting in extensive annual reports which included the descriptions of fossils by Cope (1871, 1877), Leidy (1872) and Peale (1879). Cope (1877) was the first to describe 16 species of fossil fish from Green River beds near Fossil, Wyoming (at the base of Fossil Butte). A. C. Peale, geologist of the Green River division, reported (1879) the first geologic description of Fossil Butte, located near the center of Fossil Basin (today Fossil Butte National Monument, 10 mi W of Kemmerer, Wyoming, on Highway 30) and included a description of an abundant fossil fish fauna discovered there.

Also very active in those early years was Prof. O. C. Marsh of Yale College who in 1868 visited the Green River Basin and explored it in 1870 "when he traced its deposits for several hundred miles, and from the rich vertebrate fauna fully determined its Eocene age" and recognized the lacustrine nature of its sediments (Marsh 1871a,b; 1875). Powell (1876) also recognized the Green River sediments as representing lake deposits. By 1875, 150 species of fossil vertebrates had been found, and according to Marsh (1875) constituted the conclusive proof of the Eocene age of these sediments. Many plant fossils were also uncovered and described in the late 1800's by Lesqueroux (1883), Newberry (1898), and Cockerell (1927) and Knowlton (1923) in the 1920's (MacGinitie 1969).

Hayden (1869) was the first to describe the Green River and Wasatch rock units in the Green River area, and set the basis for later stratigraphic studies in the Green River and Fossil basins. Veatch (1907) was the first to do extensive mapping of Fossil Basin and describe the geology and to such a degree that his major geologic features and most of his stratigraphic units have not been altered by later, more detailed studies (Rubey et al 1975). Schultz (1914), who was one of Veatch's associates in 1905, published a map of a large area in the northeast of Fossil Butte which they studied during 1906, emphasizing the structure of the region. Although his specific collecting localities are not well known, apparently Brown (1929, 1934) was the first to collect and describe fossil plants from Fossil Basin and from which he interpreted the plant communities around Fossil Lake.

These studies were complemented and succeeded by numerous investigations on the general geology and stratigraphy of the Green River Formation in the Green River Basin as summarized by Bradley (1964). The richness of well preserved fossil fish, vertebrates, invertebrates including extraordinary insects, and an abundant mega and microflora attracted the attention of many workers who collected and described them.

Sears and Bradley (1924), and later Bradley (1964) published their description of the stratigraphic relations of the Green River Formation. Subsequent research on the geology of the Green River Formation has been concentrated mainly in the Green River Basin just east of Fossil Basin.

More recently Rubey et al (1968a,b) mapped the north part of Fossil Basin and Oriel and Tracey (1970) described the Cretaceous and Tertiary stratigraphy of Fossil Basin including the Green River Formation. They subdivided the Green River Formation in Fossil Basin into the Fossil Butte and Angelo Members.

McGrew and Casilliano (1975) summarized the paleontology of Fossil Basin and discussed the paleoecology and taphonomy of the fossil fishes. Grande (1980) provided a rather complete catalogue and description of the fossils of the basin as well as other Green River Formation basins in Wyoming, Colorado, and Utah.

Rubey et al (1975) published a detailed map of the Sage and Kemmerer Quadrangles, which includes the northern part of Fossil Basin, along with a concise description of the geology. From their studies they tentatively assigned a middle to late early Eocene age to the Green River sediments. Cushman (1983) interpreted the palynoflora of the Fossil Butte member in his study of the depositional environments, paleoecology and paleoclimatology of these sediments in Fossil Basin.

From recent work in Fossil Basin, Buchheim (1982, 1983a,b) and Buchheim and Eugster (1986) described the sedimentology and depositional environments of the Fossil Butte Member and divided it into the Lower, Middle and Upper Units. During the course of these studies it was discovered that the lower part of the Fossil Butte Member actually thickened into a relatively thick (200 m) unit to the south. This unit is described as the Lower Unit (Buchheim 1983b), but has not been studied in the southern part of Fossil Basin. Preliminary work has revealed that this unit contains abundant fossil fish and represents a lake that existed earlier and had a depocenter further to the south than the main body of the Fossil Butte Member.

This study proposes to complement these more recent investigations and provide a more complete picture of the depositional environments and paleoecology of the Green River Formation in Fossil Basin.

Aims and Objectives

The primary objective of this study was to reconstruct the paleogeography, depositional environments, and paleoecology of a sedimentary basin that records one of the most complete sequences of lacustrine facies and contains an abundant fauna. Specific objectives were: a) to study and measure selected stratigraphic sections representing the major subenvironments within the Lower Unit of the Fossil Butte Member of the Green River Formation in Fossil Basin; b) to determine the stratigraphic relationship of the different facies established from field and laboratory analysis, as well as their relation to the fossils encountered; c) this information would aid in establishing the geographical distribution of Fossil Lake since its origin and through Lower Unit time; d) the determination of lithofacies and their interrelationships as well as the depositional facies at work in the basin would further our understanding of the depositional environments and processes operating during Lower Unit time.

A secondary goal was to better understand the paleoecological distribution of fossil organisms in Fossil Basin, and their relation to localized depositional environments.

Geologic and Geographic Setting

Location and Accessibility

Fossil Basin is located in the extreme southwestern Wyoming in Lincoln and Uinta counties, near the Utah-Idaho border (Figures 1, 2) with Fossil Butte National Monument lying approximately at its center, where it constitutes one of the best exposed outcrops of the Green River Formation.

The majority of Fossil Basin land is managed by the BLM and Fossil Butte National Monument, which facilitates access to the different study localities. Nevertheless some of it is private property and it is delineated in the BLM land use map. All of the

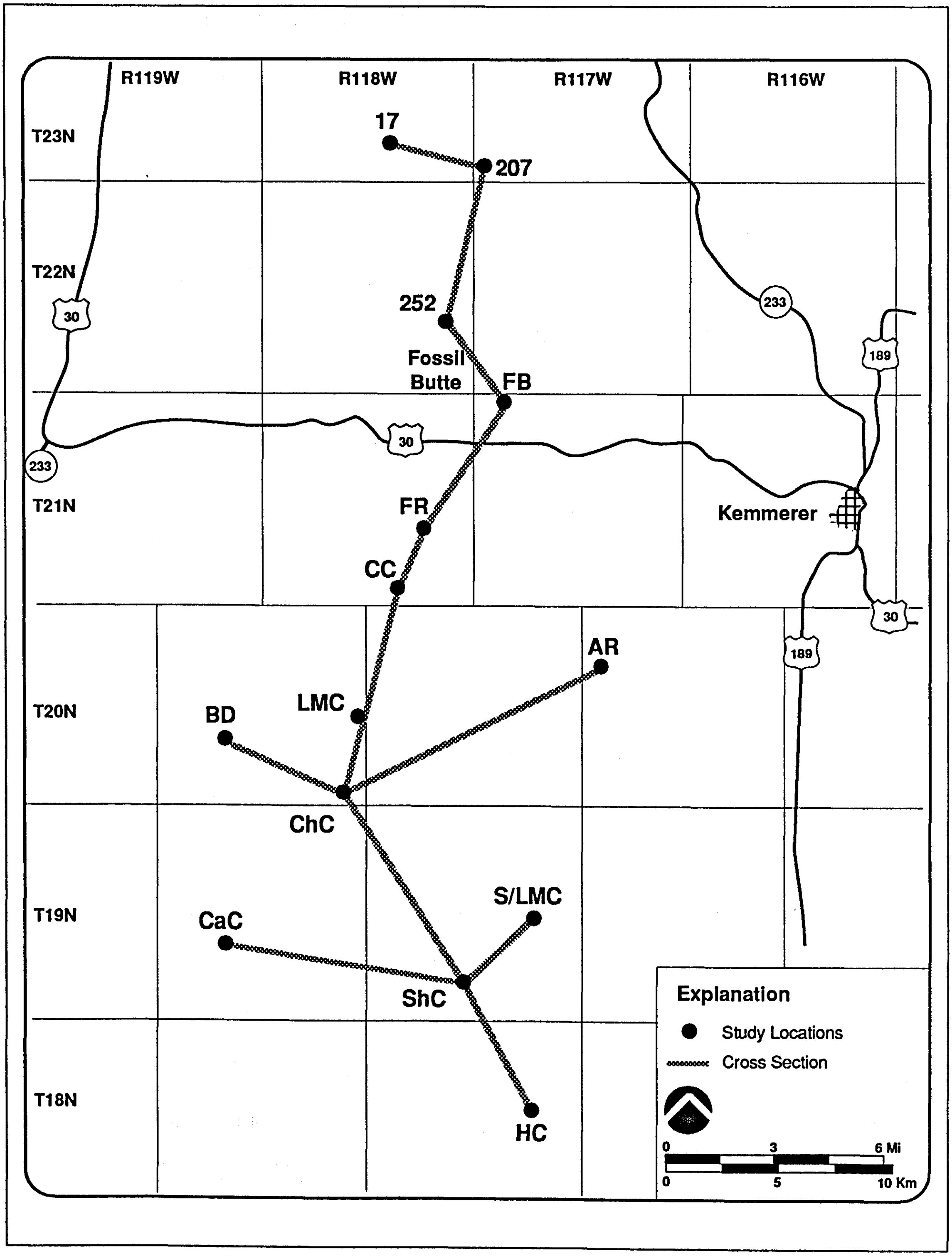


Figure 2. Location of study localities and measured sections of this study. Note north-south and two west-east lines of stratigraphic correlation.

localities, usually at outcrops well exposed along ridges, have access through BLM or oil company roads and the ranchers in the area are friendly and cooperative.

GEOLOGIC STRUCTURE

Fossil Basin is a small, linear and structurally controlled basin (called the "Fossil syncline" by Veatch, 1907) on the SE edge of the Wyoming thrust belt. Its western margin is bounded by the Tunp Range to the North and a series of ridges east of the Crawford Mountains to the South. The eastern boundary is formed by the prominent north-trending Oyster Ridge (mainly Mesozoic rocks) which formed a topographic barrier between Fossil Basin and the Green River Basin during most of the deposition of the Tertiary sediments, although the lake may have been connected briefly with the Eocene Gosiute lake in the Green River Basin. The southern margin is determined by the Uinta Mountains (Oriel and Tracey 1970).

While the structural basin was forming, clastic fluvial sediments consisting of muds, clays, sands and gravels accumulated forming the Upper Cretaceous-Lower Tertiary units such as the Adaville Formation which suffered intense structural deformation. East-west compressional forces caused north-south trending folds and thrust faults, the youngest ones being generated in an eastward direction. Further folding and faulting (post-Absaroka Thrust deformation) caused further downwarping of the incipient Fossil Basin and resulted in the accumulation of Tertiary sediments: a marginal clastic facies, the Wasatch Formation of a mainly typical fluvial nature, and a lacustrine facies in the central portion of the basin which constitutes the Green River Formation (Oriel and Tracey 1970; McGrew and Casilliano 1975).

STRATIGRAPHY

The Green River Formation was originally named and described by Hayden (1869 p. 90-91). In his report he described the sediments just east of Rock Spring Station as a new group composed of "thinly laminated chalky shales" and best exposed along the Green River. He then stated: "They are evidently of purely fresh water origin and of middle Tertiary age. The layers are nearly horizontal and, as shown in the valley of Green River, present a peculiarly banded appearance. When carefully studied these shales will form one of the most interesting groups in the west." Further, he also stated that: "One of the marked features of this group is the great amount of combustible or petroleum shales, some portions of which burn with great readiness and have been used for fuel in stoves." And indeed these shales have become a very important resource, since shale oil reserves have been estimated of about two trillion barrels of oil equivalent (Newman 1980).

Although Engelman (1859) was the first to mention and report on the geology of the "Tertiary Green River formation" in the western part of the Green River Basin, his descriptions included what is now considered Wasatch and Bridger formations. Hayden's Green River Formation could be correlated to Engelmans '2nd series' (Veatch 1907; Bradley 1964). The Green River Formation, characterized mainly by its light color and continuous bedding typical of the Lower Eocene sediments, accumulated in the lake basins of Utah, Colorado, and Wyoming (Figure 3). In Fossil Basin the Green River Formation has been divided by Oriel and Tracey (1970) into two members: the lower Fossil Butte Member and an upper unit, the Angelo Member (Figure 4).

The Fossil Butte Member was named for excellent exposures along the southern edge of Fossil Butte (Figure 5A), in what is now Fossil Butte National Monument and along the north and east ridges of Fossil Ridge, just south of the monument, where the most extensive fossil fish quarries are found. Cope (1879) collected fossil fish from here and as Veatch (1907) stated of the cliffs around Fossil, on the Oregon Short Line (railroad):

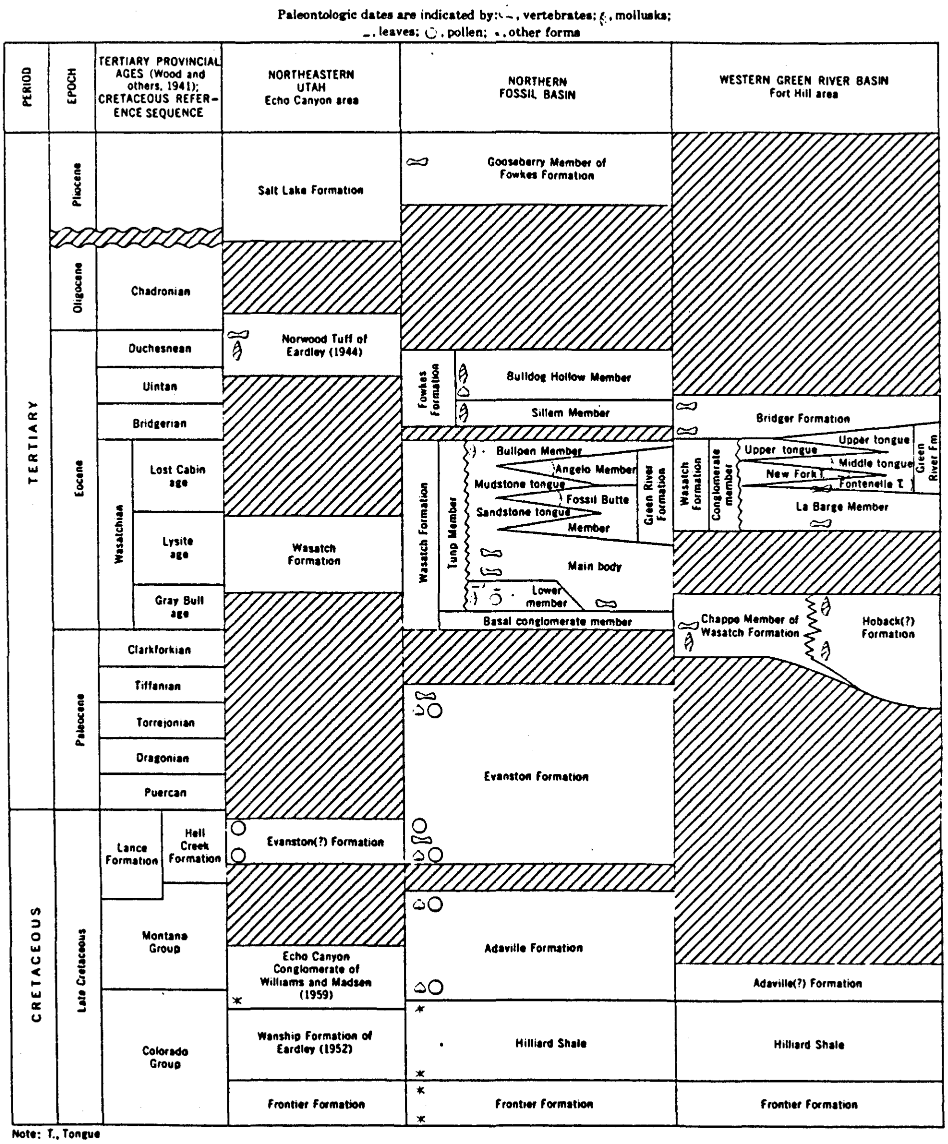


Figure 3. Approximate ages of the stratigraphic units in the Fossil Basin and adjoining areas. From Oriel and Tracey (1970).

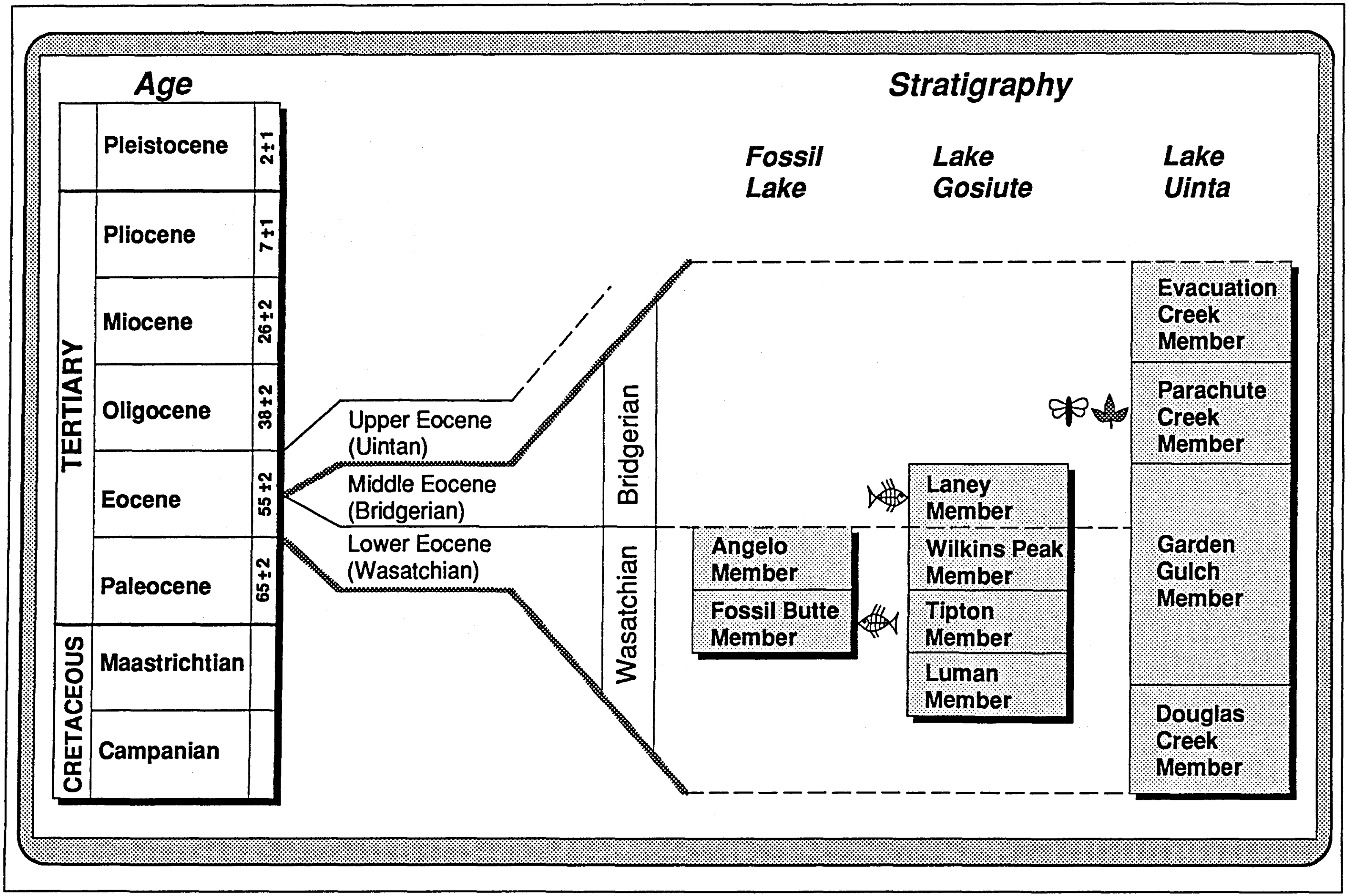


Figure 4. Stratigraphic correlation between sediments of Fossil Lake and lakes Gosiute and Uinta. Translated from Siber (1982).

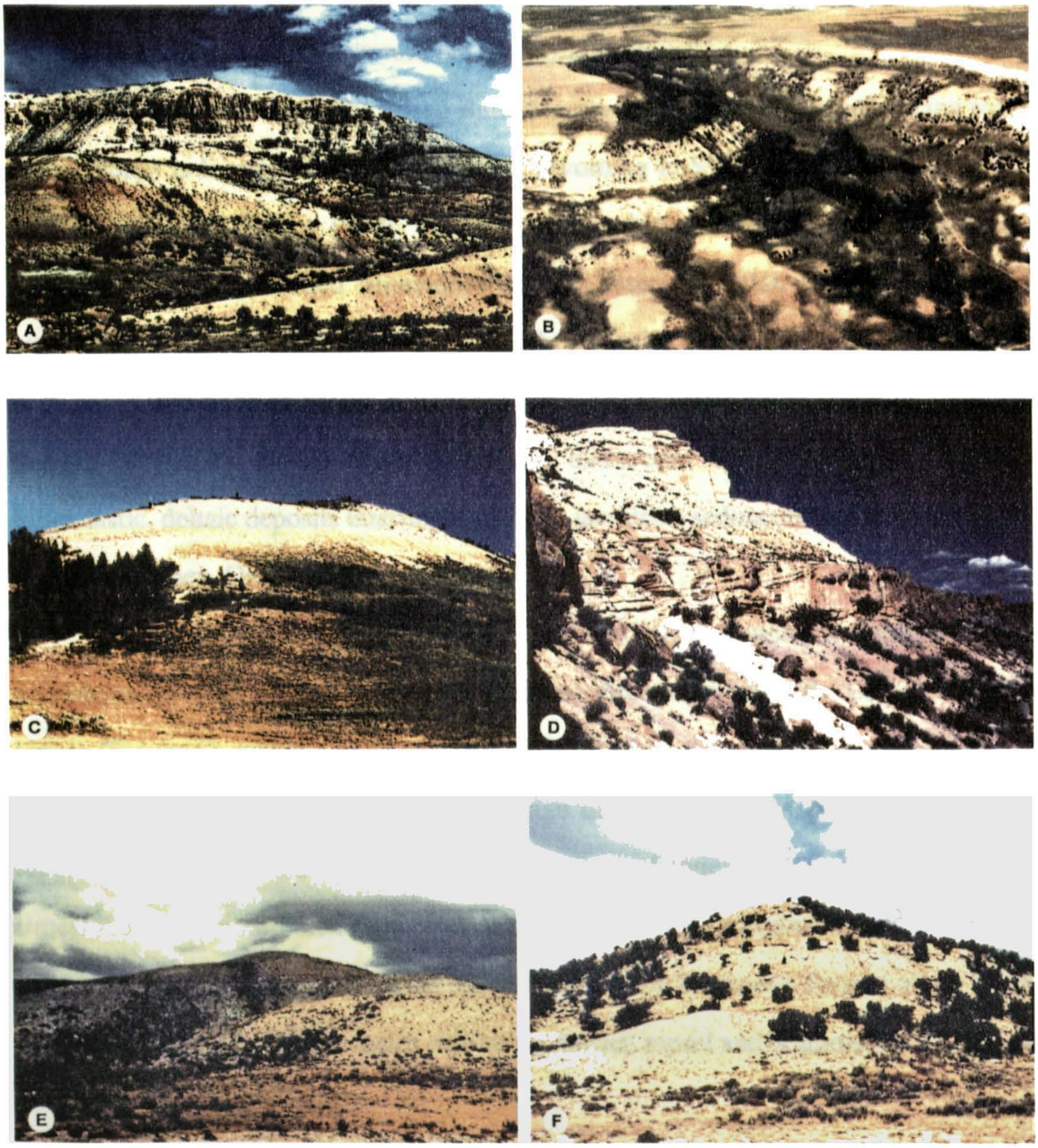


Figure 5. Some of the study localities. A. Fossil Butte. B. The northern part of Fossil Basin near locality 17. C. Fossil Ridge. D. Angelo Ranch, showing cross-bedded deltaic sandstone in the upper part of the Lower Unit. E. Sheep Creek, and F. Hill Creek, both in the southern region of Fossil Basin.

"Great quarries have been opened here, following the most fossiliferous strata for miles around the hillside, and the museums of the world supplied."

The type section for the Fossil Butte Member (east end of the south-facing scarp of Fossil Butte) is located west of Kemmerer, Wyoming in SW 1/4, NW 1/4, Sec 5, T21N, R117W (Oriel and Tracey 1970). Fossil Butte Member consists mainly of tan and brown weathering buff laminated limestones and marlstones, bluish-grey to bluish-white-weathering brown to black oil shale, and light-grey siltstones, mudstones and claystones with some thin beds of brown tuffaceous ash. These rocks grade laterally towards the margin of ancient Fossil Lake into algal, ostracodal and gastropodal limestones. Siliciclastic, deltaic deposits interfinger with the lacustrine sediments towards the margin of the basin (Rubey, Oriel and Tracey 1975).

Buchheim and Eugster (1989, in preparation) following a natural lithologic breakdown, divided the Fossil Butte Member into three major units, the Lower, Middle and Upper (Figure 6), which can be correlated with distinct depositional environments. The Lower Unit, which represents the first stage of Fossil Lake is not a well developed lacustrine sequence and consists of siliciclastic mudstones and sandstones, ostracodal limestones, and bioturbated calci- and dolomicrites. In the marginal areas of Fossil Lake the Lower Unit is separated from the Middle Unit by the Sandstone Tongue of the Wasatch Formation. This is a deltaic facies exhibiting foreset, topset and bottomset beds (Peterson, 1987).

The Middle Unit is a well developed lacustrine sequence and it is best developed and exposed at the Fossil Butte Member type section, and consists primarily of laminated kerogen-rich micrite (oil-shale), with abundant fossil fish, insects and plants. This unit contains two distinct sets of tuffs separated by about one meter which have been called the Sandwich Horizon by Buchheim and Eugster and is an important correlation unit through the basin. The Middle Unit is separated from the Upper Unit by a most easily correlatable

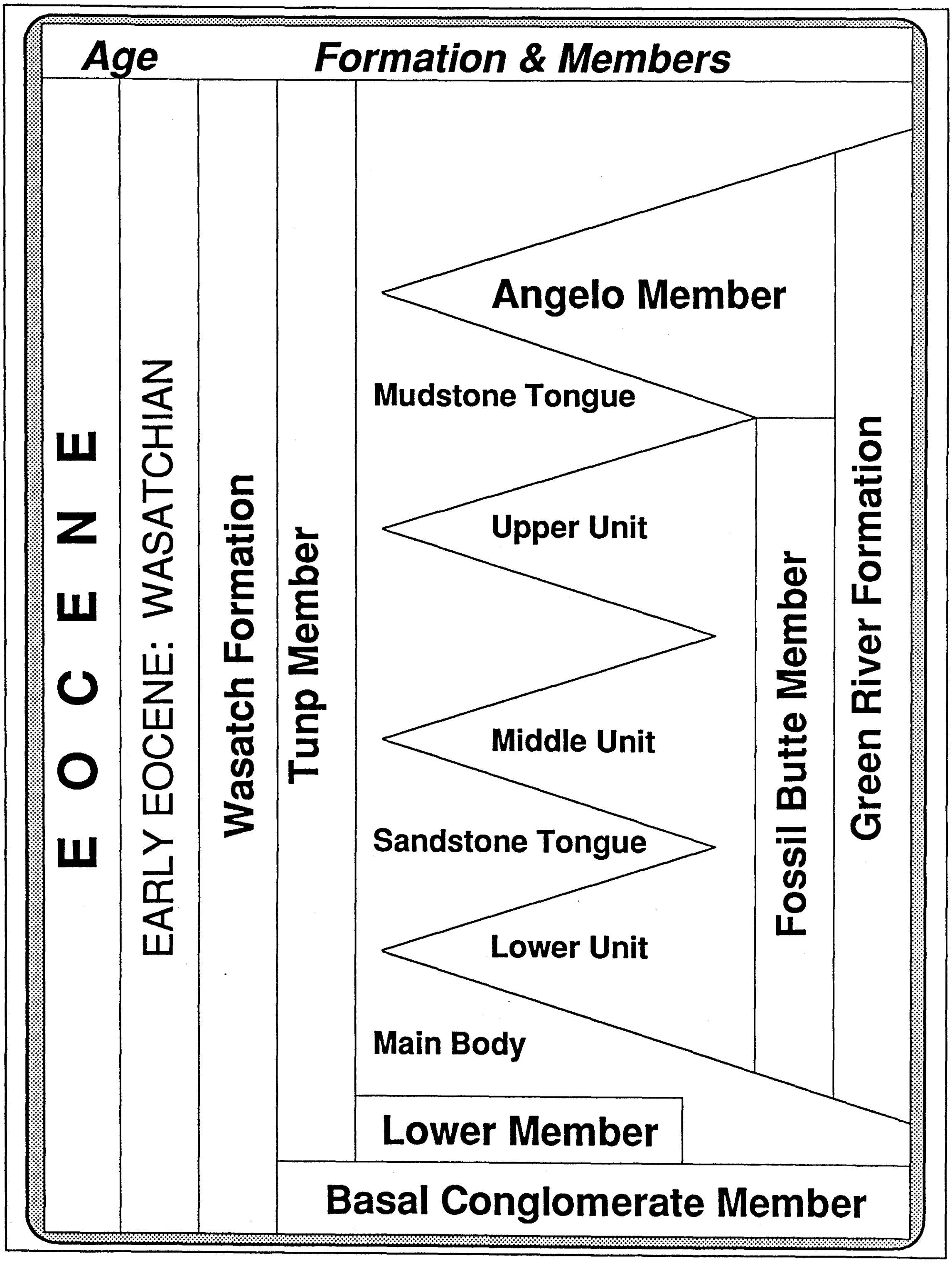


Figure 6. Stratigraphic units of the Green River and associated Wasatch formations in Fossil Basin. Revised from Oriel and Tracey (1970).

horizon, the "K-spar Zone" (Buchheim and Eugster, 1989 in preparation) which is capped by a distinctive 15cm-thick pink potassium-feldspar tuff ("K-spar tuff").

The Upper Unit is characterized by the presence of calcite pseudomorphs after saline minerals in the laminated dolomicrites, some of which are petroliferous.

Buchheim and Eugster (1989, in preparation) have studied in detail the depositional environments in relation to the oil-shale origin and occurrence, especially abundant in the Middle Unit of the Fossil Butte Member. Subsequent field studies in Fossil Basin have demonstrated the presence of a much more well developed lacustrine sequence than previously thought for the Lower Unit time period. Some well-developed oil-shales with abundant fish remains have been discovered south of Fossil Butte which would indicate the possibility of a more southerly lake depocenter for the Lower Unit deposition (Buchheim and Eugster, 1989, in preparation). They found that the Lower Unit is thickest in the southern half of the basin, with the best developed lacustrine facies occurring at Clear Creek (see Frontispiece), while at Fossil Butte it thins rapidly and is replaced by the Wasatch Formation in the form of a dominantly siliciclastic unit, the Sandstone Tongue, composed of a four meter sequence of alternating siliciclastic mudstone and laminated micrite. Further north the Sandstone Tongue equivalent is represented by a mudstone unit about a meter thick which indicates a rapidly changing facies (Buchheim and Eugster, 1989, in preparation). This study was restricted to rocks of the Lower Unit of the Fossil Butte Member in the southern half of Fossil Basin.

FOSSILS AND AGE

Probably the most attractive character of the Fossil Butte Member deposits, which has made Fossil Butte famous all over the world, is the fantastic occurrence of beautifully preserved fossil fish. In some areas the Green River shales contain millions of excellent specimens, and have been quarried extensively since the late 1800's in the Fossil Butte area. Furthermore the Fossil Butte Member has yielded such a variety of fossil invertebrates, vertebrates and plants that the fossil assemblage could be considered one of the best preserved and most extensive known in North America. Nevertheless the precise age of the member has remained uncertain due to the lack of comparable reference material (Oriel and Tracey, 1970). Because of this problem, dating has been restricted to the intertonguing Wasatch sediments which have yielded an abundant mammalian fauna (Gazin, 1959).

In his study of the palynoflora of the Fossil Butte Member, Cushman (1983) found it to represent an early to middle Eocene age (i.e. late Lostcabinian to early Bridgerian). He complemented his findings with a potassium-argon age determination requested by Buchheim and Eugster (1989, in preparation) by Geochron Laboratory on a sample of feldspar from the "K-spar tuff" near the top of the Middle Unit of the Member, that yielded an age of 49.1±1.8 MY, age which represents the start of Bridgerian time. This allowed him to correlate with reasonable certainty the majority of the Fossil Butte Member sediments with those of the Wilkins Peak member in the Green River Basin. And based on sedimentological evidence he predicted that the lower boundary of the Fossil Butte Member would be equivalent to some portion of the Tipton Shale Member (Cushman, 1983).

MATERIALS AND METHODS

Nine stratigraphic sections of the Lower Unit (Fossil Butte Member, Green River Formation) were measured in the southern half of the depositional basin. After a preliminary correlation of these sections to determine the depocenter and marginal sections, six of these sections representing the depocenter, intermediate and marginal facies were sampled. Over 200 samples were collected, consisting primarily of the lacustrine carbonates and carbonate bearing sediments present. These samples reflect the paleochemical character of the Fossil Lake waters and thus provided insights into the nature of the paleoenvironments under which these sediments were deposited. Whenever appropriate, fossils present were recorded and significant specimens were collected. In addition, other sections were studied especially in the southernmost reaches of the basin in order to determine the extent of the lake during Lower Unit time. During preliminary survey of the southern reaches of Fossil Basin, it became apparent that interesting relationships existed in those regions. The lithologic character, sedimentary structures, and paleontology of the individual sedimentary units were recorded (Appendices 1 and 2).

As already noted by Buchheim and Eugster (1986) the Fossil Butte Member sediments have typically resulted from cyclic deposition. One of the stratigraphic sections (ChC) was sampled in its entirety such as to record in detail the occurrence of any cycles present. Markov Chain Analysis was applied to all sections to establish the lithofacies assemblage and relationships and to determine the occurrence and nature of cyclic events. The method used is that recommended by Miall (1984) and procedures follow those of Reading (1978), Walker (1979) and Miall (1973, 1980, 1984). Computations can be found in Appendix 4.

Laboratory analysis of the lithologic samples included X-Ray diffraction analysis on 51 samples, using standard XRD techniques, and mineral % were estimated using comparative peak heights (XRD data is included in Appendix 3), sample slabbing, acid etching, and staining (to study sedimentary structures), and petrographic analysis of selected samples. Mineralogic and lithologic data were plotted in a vertical profile along side paleontologic data. Comparison between these data were made to relate vertical changes in fauna to vertical changes in sedimentation. For example, a vertical change from calcite to dolomite may represent a dramatic increase in salinity that can be related in turn to faunal changes, since fish as well as gastropods, etc. are affected by water chemistry. Sedimentary structures in the same profile indicates depositional conditions such as water depth and velocity, e.g. river v.s. lake deposition.

A lithofacies cross-section diagram was constructed from lithofacies data obtained from stratigraphic sections and correlation of these sections. In addition, a paleogeographic depositional facies model diagram was developed from basin analysis maps such as isolith maps of carbonates, carbonate/siliciclastic ratio, prograding fluvial-lacustrine wedges, and isopach maps showing gross thickness of lacustrine and fluvial rocks to better understand the paleoenvironments present in Fossil Basin during Lower Unit time.

The facies maps and diagrams along with analysis of the vertical lithologic, mineralogic, and paleontologic profiles allowed significant interpretations concerning the paleoecology and paleogeography of the Lower Unit sediments deposited in Fossil Lake.

RESULTS

CHARACTER OF LAKE DEPOSITS

To gain a better understanding of sedimentary interrelationships and paleoenvironments, a precise knowledge of the basic lithofacies and facies associations is necessary. Studies which have emphasized the petrographic description of carbonate rocks of the Green River Formation (such as Piccard et al, 1973; Williamson and Piccard, 1974) have provided conventional descriptions of the rocks which demonstrate the diversity of carbonate lithologies deposited in that lacustrine environment. Most use 'conventional' rock classifications and nomenclature which are restrictive in their value as paleoenvironmental indicators. In the present investigation, a facies analysis approach was used which in contrast with a conventional-traditional descriptive lithostratigraphic study, it is based on detailed lithofacies descriptions, which become the basis for the genetic study of sediments. Each lithofacies represents an individual depositional event. In turn lithofacies are grouped in lithofacies associations or assemblages which reflect a particular depositional environment. The lithologic nomenclature and classification followed in this report is that of Buchheim and Eugster (1989, in preparation) which better describes the nature of the Fossil Basin carbonate rocks. It is based on mineralogy, kerogen content, grain size and sedimentary structures, thus rocks become descriptors of their nature and provide clues with respect to their depositional environment.

LITHOFACIES

The Lower Unit of the Fossil Butte Member of the Green River Formation in Fossil Basin is mostly dominated by siliciclastics, although in some sections the carbonate fraction can be more than 50% (Table I) This is directly related to the facies pattern found in Fossil Basin (i.e. carbonates are much more abundant in the depocenter which was dominated by an open lacustrine environment). The most common carbonate lithotypes in the Lower

Table 1
List of lithologies found in Fossil Basin (Nomenclature after Buchheim and Eugster, 1989, in preparation)

Carbonates

Mic: Micrite, massive
LM: Laminated micrite

- **KRLM:** Kerogen Rich Laminated Calcimicrite
- **KRLD:** Kerogen Rich Laminated Dolomicrite
- **KPLM:** Kerogen Poor Laminated Calcimicrite
- **KPLD:** Kerogen Poor Laminated Dolomicrite
- **KPLMSil:** Kerogen Poor Laminated Calcimicrite with significant amount of quartz

LS: Limestone: Gastropodal and Ostracodal

Tufa

Siliciclastics

SS: Sandstone
Slst: Siltstone
MS: Mudstone

Other

Chert
Tuff: Altered to Analcime
Potassium Feldspar

Unit are kerogen-rich laminated micrites ("oil shale", KRLM), kerogen-poor laminated micrite (KPLM), bioturbated or massive micrite, dolomicrite, siliciclastic sandstone, siltstone and mudstone, and volcanic tuff. Variations in these major groups occur and are included in the descriptions.

Micrites

Micrites can be massive or laminated, either can become bioturbated, contain a varying amount of organics (kerogen), siliciclastic material, fossils, calcite, and dolomite. Laminated micrites constitute ca. 50% of the carbonates, and appear as a wide spectrum of carbonates ranging from buff-light colored to brown, friable slope forming sediments to dark brown to black, well indurated ledge forming rocks.

Kerogen-poor laminated micrite (KPLM) (Figure 7E)

These laminated micrites are the most common laminated sediments in Fossil Basin and the light-colored kerogen poor equivalent of the kerogen rich oil shales into which they grade towards the basin center. Laminations consist of couplets 0.1-1.0mm of alternating kerogenous and carbonate rich laminae. The organic laminae, usually orange to brown in color, are more or less continuous, and range from 0.02-0.04mm in thickness. Mineral laminae are composed mostly of calcite grains and minor amounts of quartz and dolomite. XRD mineralogy analysis shows calcite as the principal mineral in all KPLM (60-95%). Calcite grains range in size from 3-20 micrometers and can show fining up gradation which in some cases is the sole laminae determinant. The laminae pinch and swell laterally, and in general are thicker than oil shale laminites.

In several sections such as FB, BD and ChC, KPLM alternate with laminated claystone in cyclic sequences of dark brown color which form recognizable bands in outcrops.

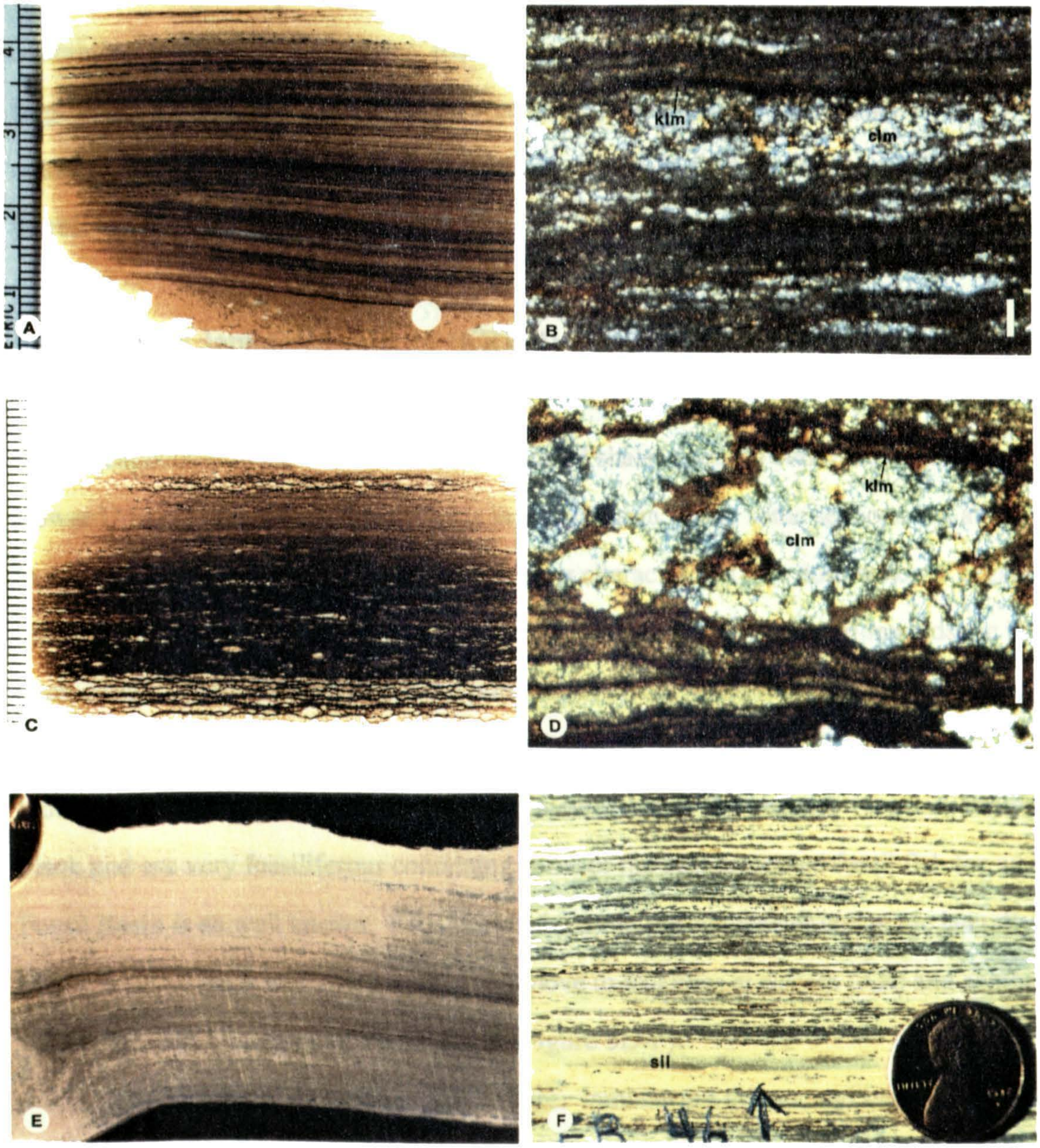


Figure 7. Lithofacies of the Lower Unit. A-D. Kerogen rich laminated micrite (KRLM). Dark kerogen laminae (klm) alternate with lighter calcite laminae (clm). A, C, small divisions on scale = 1 mm; B, D, scale bar = 0.1 mm; A-B, CC-07; C-D, CC-11. E. Kerogen poor laminated micrite (KPLM) from ChC-14. F. A peculiar type of quartz rich kerogen poor laminated micrite (KPLMSil) showing siliceous (sil) alternating laminae; from FB-46.

Although of poor kerogen content these micrites can be very fossiliferous containing gastropods, ostracodes, fossil fish, coprolites, plant fragments and other fossil fragments. Ostracodes seem to be very common throughout these sediments and usually occur in the interlaminae planes. In addition, some of these units can exhibit a strong petroleum odor when sediments are broken up.

Kerogen-rich laminated micrite (KRLM; "oil shale") (Figure 7A-D)

Although not as abundant as in the Middle Unit and other Green River Formation basins (especially in the Uinta Basin) in which oil shales occur in commercial quantities, Lower Unit oil shales form distinct beds in Fossil Basin and in some sections can attain up to one meter thicknesses. Oil shale deposition is characterized by a dominance of organic material, by thinner and darker lamination, and are typically concentrated towards the basin depo-center. Also characteristic is the presence of a well preserved fossil flora and fauna. Along CC and other sections in the center of the basin, they form resistant and well indurated ledges, in one instance up to three meters thick. They appear very dark brown to black and are very fossiliferous containing some of the best preserved fossil fish for which Fossil Basin is so well known. KRLM are thickest in the depocenter and grade laterally into KPLM. This is well evidenced as you move to localities at eastern (AR) and southern (CaC, HC, ShC) margins of Fossil Basin (Figure 5D-F).

The major differences with KPLM are: laminae are thinner and kerogen content is greater making them much darker in color (some are almost black). Laminae thickness ranges between 0.05-1.0mm. They occur as couplets of thinner Kerogen dominant and thicker mineral dominant laminae, kerogen being abundant throughout.

Mineralogy of Lower Unit oil shales consists of mostly calcite crystals (up to 95%)(KRL calcimicrites: KRLM) in contrast with the Upper Unit oil shales which are dominated by dolomite and quartz (KRL dolomicrites: KRLD) In addition some laminations might be aragonitic. Such is the case with ChC--71, a thick (1.1m) oil shale unit (ledge former) in which laminae are aragonitic and consist of 75% aragonite, 20% calcite and minor amounts of quartz.

Organic content varies with the location and can be as high as 12% TOC (Buchheim and Eugster 1989, in preparation).

Beds not well lithified usually exhibit parting which is commonly shaly, where laminated micrites break into fairly uniform plates .1-1.0 cm thick. Many kerogen rich and kerogen poor laminated micrites show papery parting (paper shales) and commonly break into plates thinner than one millimeter uncovering exquisitely preserved fossil fish, plants and insects.

Burrowed laminated micrite (Figure 8A-B)

Tubular structures are present in several laminated micrites at marginal localities such as Hill Creek and Angelo Ranch, and can be vertical, horizontal and branching.

Kerogen-poor laminated siliciclastic-calcitic micrite (KPLMSil)(Figure 7F)

This variation of KPLM is well developed at the top of the Lower Unit at FB, where alternating micrite and claystone form a dark four meter band which is readily recognizable in the outcrop. In this peculiar laminated micrite, mineralogy is dominated by calcite, with a high amount of quartz (from 20-45%). It constitutes a significant, although not abundant lithofacies in the Lower Unit. At several localities (FB, BD, ChC) this lithofacies appears as thick brown bands, which at close examination consist of cyclic alternating laminae and beds of KRLM to KPLM and claystone, all with varying amounts of calcite, dolomite and quartz.

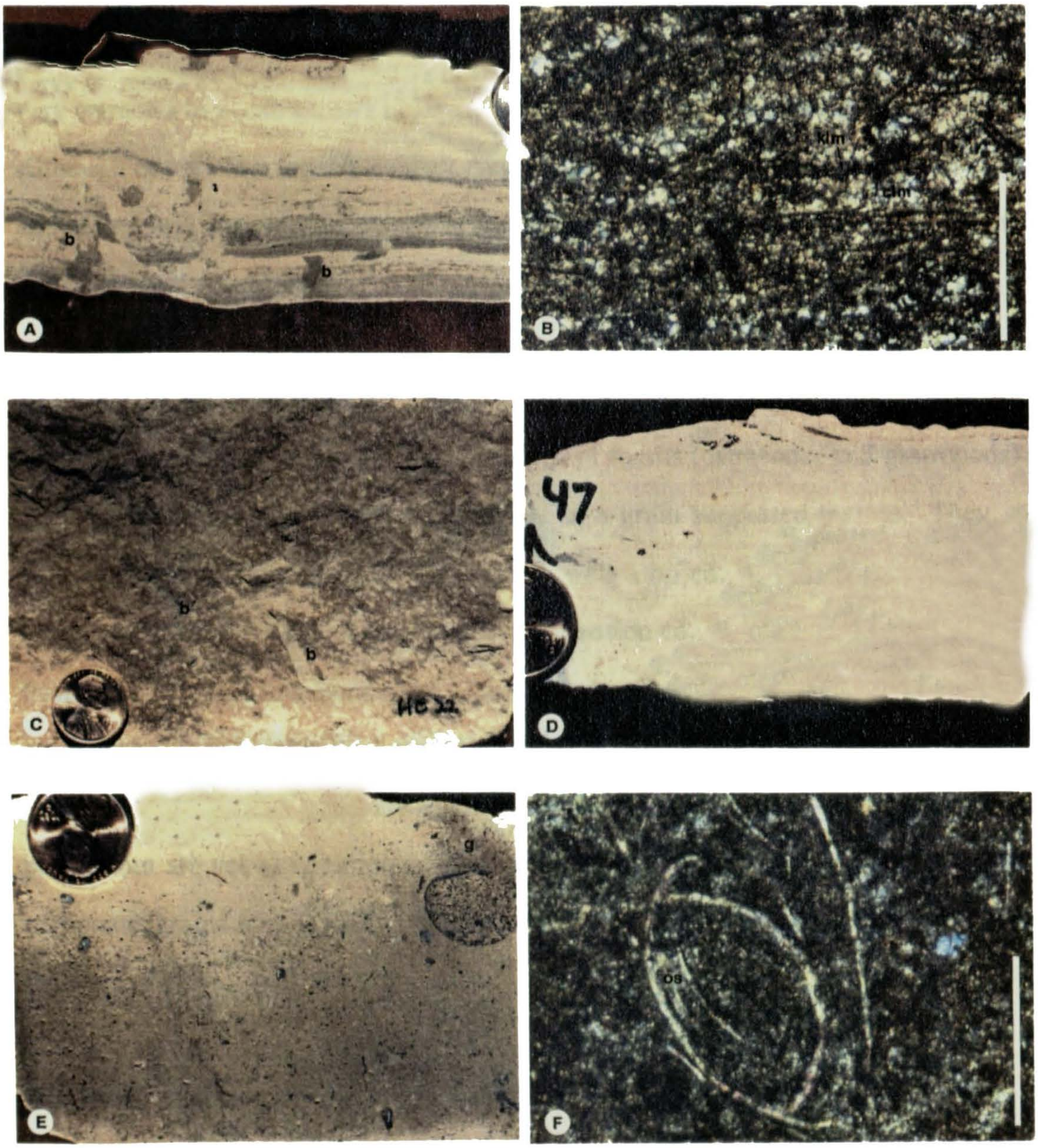


Figure 8. Lithofacies of the Lower Unit (continued). A-B. Bioturbated kerogen poor laminated micrite showing burrows (b) and disrupted kerogen (klm) and calcite (clm) laminae; B, scale bar = 0.5 mm, A-B from ChC-87. C-D. Bioturbated micrite showing burrows (b) and dololmite intraclasts (d); C, HC-22, D, ChC-47. E. Gastropod (g) in a gastropodal limestone from ShC-09. F. Ostracodal limestone showing ostracode shells (os), HC-32, scale bar = 0.5 mm.

Non-laminated or bioturbated calcimicrite (Mic)(Figure 8D)

These bedded to massive, buff-cream colored, porous and friable chalky rocks are very common in Fossil Basin's Lower Unit and are mostly common at marginal localities. Although of very low organic content they can contain fossil fish fragments such as bones and scales, and occasionally complete specimens, as well as fossil gastropods, ostracodes and occasional pelecypods.

Biomicrites (Ostracodal and gastropodal limestones) (LS)(Figures 8E-F, 9A-B)

These carbonates are mostly composed of fossils (ostracodes and gastropods) and micrite-microspar-clay. About one half are of a grain supported texture. They are in general well indurated and in some sections well lithified, and form prominent ledges. Many of the benches which develop through erosion along ridges in Fossil Basin result from these resistant limestone units. They are of a wide range of colors (from buff-tan to gray), with the majority in the Lower Unit being of a light-yellow-tan color.

Most abundant fossils are ostracodes and gastropods. Pelecypods are occasionally present but are not as common in these rocks. An average biomicrite contains 90-95% carbonate grains and fossils, 1-5% quartz, 1-3% opaque minerals (pyrite) and trace amounts of clays.

Dolomicrite

Although more common in the Middle and Upper Units of Fossil Butte Member some dolomicrites are present in the Lower Unit. Dolomite appears in several lithofacies but does not constitute a significant and distinct facies. They are usually thin light colored beds of chalky appearance. Mineralogically they consist of 60-90% dolomite with minor amounts of calcite and quartz. In the lower half of the basin it occurs as thin beds of dolomicrite usually associated with ostracode remains. In several sections such as Bear

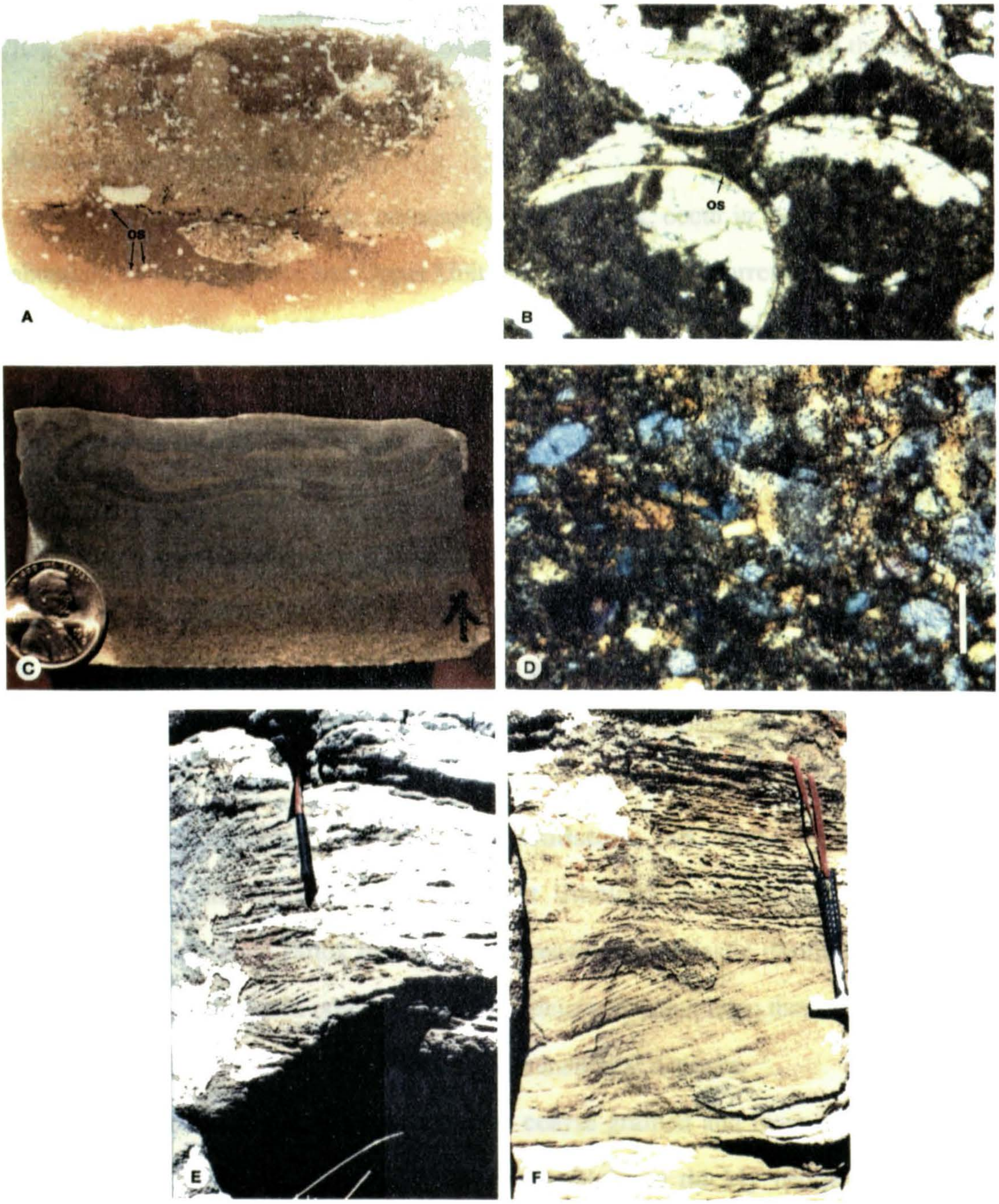


Figure 9. Lithofacies of the Lower Unit (continued). A-B. Abundant ostracodes (os) one mm in length dominate this ostracodal limestone, S/LMC-40. C-D. Analcimic tuff from CC-04, bar scale = 0.1 mm. E-F. Sandstone outcrops from LMC and HC respectively.

Divide, Clear Creek and Angelo Ranch there are a few beds dominated by dolomite (up to 70%), and occurring typically in the Lower Shale subunit, near the base of the section.

Volcanic Tuffs (Figure 9C-D)

Thin volcanic tuff beds, commonly .5-2cm thick, occur in the Lower Unit. Not as abundant as in the Middle and Upper Unit they indicate the occurrence of volcanic activity throughout the history of Fossil Lake. The majority are primarily composed of analcime, and a few of authigenic potassium feldspar. Buchheim and Eugster (1989, in preparation) found that the Middle Unit tuffs are primarily composed of authigenic K-spar and analcime and the Upper Unit tuffs are authigenic K-spar and quartz. The nature of the Lower Unit tuffs corroborates a trend in tuff mineralogy through the Fossil Butte Member: from the bottom of the sequence up, analcime to analcime and authigenic K-spar in the Lower Unit, to authigenic K-spar in the Middle Unit, to authigenic K-spar with quartz in the Upper Unit, indicating a change in the chemistry of lake waters through time.

Siliciclastic Sandstone, Siltstone and Mudstone (SS, Slst, MS)(Figure 9E-F)

Siliciclastic units are the dominant lithology in the Lower Unit sequence. Siliciclastic/carbonate ratios indicate an increasing siliciclastic dominance towards the Southern part of the basin pointing to major siliciclastic input from that region. These units occur as deltaic, fluvial and fluvio-lacustrine transitional deposits.

Sandstones range from very thin to coarse grained and from light tan to gray in color. Most units are massive, some being thinly to thickly bedded. Sedimentary structures include ripple and trough crossbedding, current lineation, small and large scale planar cross bedding. At the top of the Lower Unit there is a major siliciclastic sequence, the Sandstone Tongue of the Wasatch Formation (of Oriel and Tracey, 1970). This unit has been studied in detail by Peterson (1987), were he found that two upward coarsening sequences in the Sandstone Tongue, which contain bottomset, foreset and topset beds, could be interpreted as indicative of a rapidly prograding bird's foot delta (Figure 5D).

Sandstones are dominated by subrounded to subangular quartz (20-40%) and rounded to subrounded chert (20-25%), carbonate clasts (5-15%) and minor amounts of feldspars and opaque minerals, all cemented with sparry calcite (Peterson, 1987)(Figure 9E-F).

Finer grained siltstones and mudstones are very common throughout the Lower Unit and are found interbedded with sandstones and lacustrine carbonate units. They range from light to dark, brown, green or gray, massive to bedded rocks. Although usually organic poor some mudstone units are rich in plant fragments, and can alternate in well developed cyclic sequences with kerogen poor laminated calcimicrites, forming a very noticeable usually brown band along the slope.

In addition, many thick siltstone and mudstone sequences contain thin (commonly 10-20cm, but up to one meter) sandstone interbeds through the otherwise fine grained mudrock.

FACIES RELATIONSHIPS

It is well known that lakes are among the most varied of all depositional environments, and as a result there are no universal facies models for the lacustrine environment (Miall, 1984). Based on their study of a well developed lacustrine carbonate sequence in the Middle Unit (Fossil Butte Member) Buchheim and Eugster (1989, in preparation) proposed a lithofacies assemblage and succession from KRLM-KPLM-non to well bioturbated micrite-dolomicrite which represents a lateral relationship from basin depocenter to the basin margins (Figure 10A). At the same time this pattern would indicate, in vertical succession, a lacustrine regression. Conversely a reverse sequence represents a lacustrine transgression, which in Fossil Basin is best developed during Middle Unit time,with

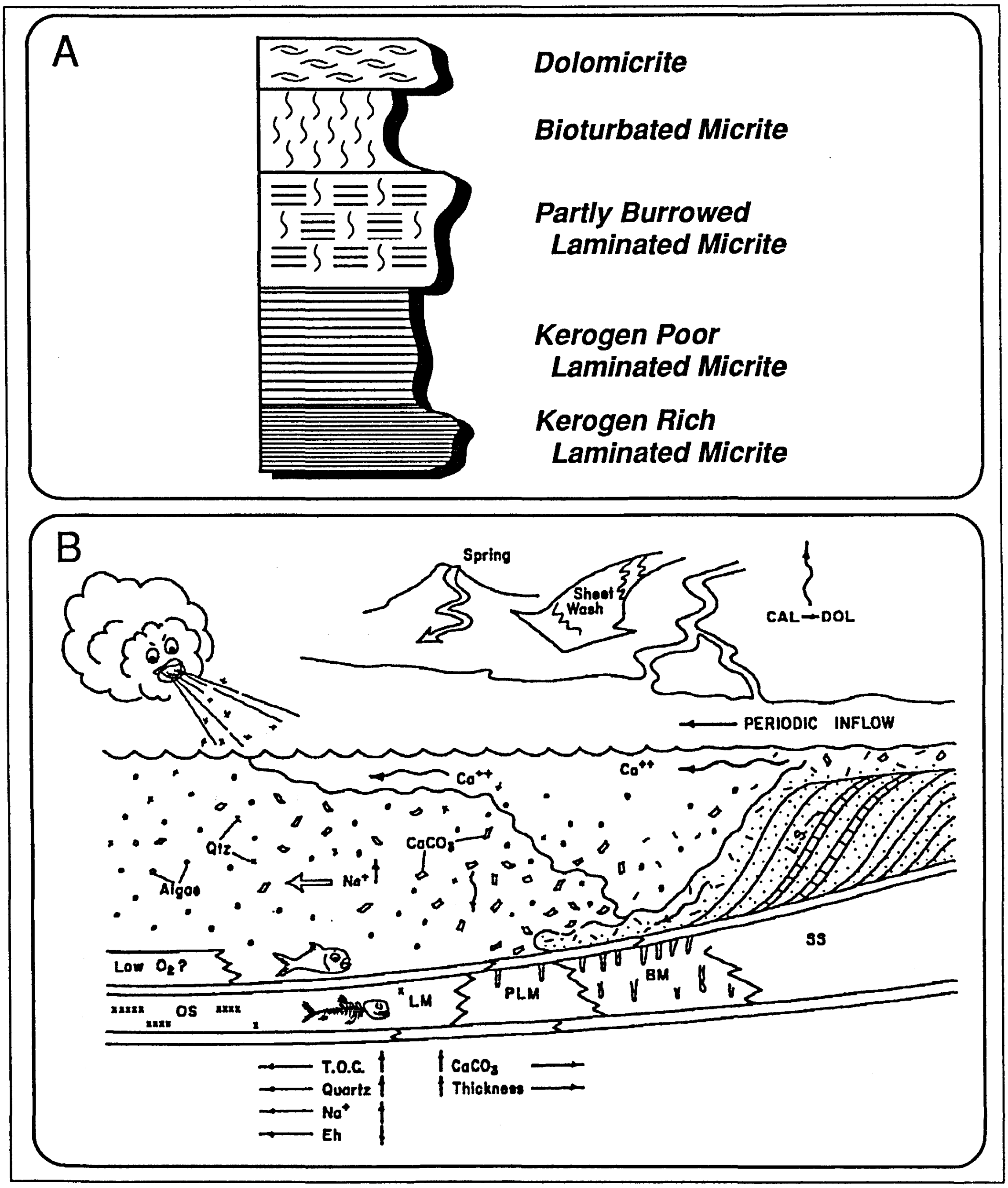


Figure 10. Buchheim and Eugster (1989, in preparation) lithofacies assemblage (A), and depositional model (B). In the model, oil shale (OS) at the depocenter, possibly anoxic, preserving fossil fish and precluding bioturbation, grades towards the margins into laminated micrites (LM), then partly burrowed laminated micrite (PLM), and near the margins into bioturbated micrites (BM), which eventually are replaced by siliciclastics. In addition the model explains organic dilution by carbonate influx.

extensive and thicker units of oil shale and laminated calcimicrites. These observations, along with integrated information from paleoecology and mineralogy, led them to the development of the facies model of figure 10B.

The Lower Unit is characterized by a dominance of siliciclastic sediments which in the central part of the basin average twice the amount of carbonates (Sil/Carbonate= ca. 2) and in the southern region reach values up to 20-25 Sil/Carbonate (See Table 2). Laminated sediments are less abundant (Table 2), and interbedding of carbonates with siliciclastic sediments is more common in a smaller scale.

In order to corroborate field observations of lithofacies relationships throughout the basin, and taking into account 1) Walther's Law: the "Rule of Succession of Facies" which succinctly can be expressed as "A conformable vertical sequence of facies was generated by a lateral sequence of environments" (Middleton, 1973) and that 2) "All sedimentation is cyclic, some more cyclic than other" (Selley, 1979), the technique of Markov chain analysis was applied to the Lower Unit sediments studied. For a detailed discussion on the use and applicability of this method see Reading (1978), Walker (1979), and Miall (1973, 1980, 1984).

The method results in a grouping of lithofacies into a lithofacies assemblage. In addition it reveals the order in which the lithofacies succeed each other. As expressed by Harbaugh and Bonham-Carter (1970, cited by Miall 1984) a Markov process is one "in which the probability of the process being in a given state at a particular time may be deduced from knowledge of the immediately preceding state."

All sections were analysed with this method and tabulations can be found in Appendix 4. Sections FB, FR, CC, BD, ChC, and AR are more centrally and northerly situated in the basin and significantly distinct from sections in the southern regions of Fossil Basin: sections CaC, ShC, S/LMC, and HC. Transition counts from these two

Table 2
Total thickness, siliciclastic and carbonate thickness tabulation, from measured stratigraphic sections in the Lower Unit

SECTION	TOTAL THICKNESS	CARBONATES	LAMINATED SEDIMENTS	OIL SHALES	SILICI-CLASTICS	SANDSTONES	SIL/CARB RATIO
Loc 17	9.09	4.92	.36/7.3%		4.17	4.10	0.85
Loc 207	3.87	3.87	.75/19/4%				
Loc 252	16.50	16.50	.5/3%				
Fossil Butte	30.15	20.76	12.3/59%	0.9	9.40	2.30	0.45
Fossil Ridge	77.33	25.89	13.7/53%	4.09	51.44	0.20	1.99
Bear Divide	143.33	54.45	34.4/63%	2.9	88.90	11.80	1.63
Clear Creek	68.06	22.62	14.5/64%	5.4	45.45	15.34	2.01
Chicken Creek	102.90	26.99	9.6/36%	2.95	75.90	15.70	2.80
Angelo Ranch	47.50	19.30	10.1/52%		28.20	13.30	1.46
Sheep Creek	76.45	4.05	3.05/75.3%	0.5	72.40	10.10	17.90
Carter Creek	107.35	3.90	1.7/45%	0.3	103.50	30.00	26.90
Sheep/Little Muddy Cr	67.80	10.60	2.8/27%	0.4	57.30	0.00	5.43
Hill Creek	104.40	4.10	2.0/50%		100.30	15.50	24.50

groups were analysed (Tables 3 and 4) and resulted in two path diagrams for each group. The first (for each group), Figure 11A and Figure 12A, is a Facies Relationship Diagram (FRD) showing the observed number of lithofacies transitions (from the Transition Count Matrix of Tables 3 and 4). After a test for non-randomness was applied (Independent Trials Probability Matrix of Tables 3 and 4) a second and simpler FRD resulted (Figures 11B-C, 12B-C), based on transitions that occur more commonly than random (positive values from Difference Matrix of Tables 3 and 4). Lithofacies assemblages were constructed after careful evaluation of path diagrams and especially of the preferred FRD's.

Several general observations are evident from these diagrams: 1) Although significantly distinct, sections of the Northern and Southern groups share similar lithofacies assemblages and successions, as revealed by the analyses which in a lacustrine transgressive sequence (or from margin to basin center) are Sandstone-Siltstone-Mudstone-Micrite-KPLM-KRLM (Figure.13). 2) Analyses demonstrate the cyclic nature of the Lower Unit sediments. 3) Diagrams also reveal the variability of the relationships, pointing to possible different pathways of facies successions. 4) When the two diagrams (Observed FRD and Preferred FRD) are compared and related to the actual stratigraphic sections, preferred relationships point to particular cyclic sequences which can be detected (for example the Mudstone-KPLM relationship in the Northern group can be traced to sequences of interbedded Mudstone and laminated micrites in the lower part of several stratigraphic sections of that area). 5) Particular relationships become readily apparent, such as the occurrence of the Limestone lithofacies and its relationship with the siliciclastic portion of the succession indicating the fluviatile nature of its environment of deposition.

This basic lithofacies assemblage can be modified according to the location of the stratigraphic sections. The best developed lacustrine sections are situated in the vicinity of Chicken Creek (ChC) where well developed laminated micrites (including oil shale) occur (Table 2). This is also the area of the thickest occurrence of oil shales. Towards the west

Table 3
Tabulation of facies relationships using Markov Chain Analysis (Embedded), Northern Localities: FB-FR-CC-BD-ChC-AR (Analysis of individual localities are found in Appendix 4)

Upper Bed

Transition Count Matrix, Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS	Row Tot
SS	0	14	13	1		3		2	33
Slst	12	0	13	6		6	1	10	48
MS	15	19	0	29	6	69	5	15	158
Mic	1	9	28	0	1	12	10	13	74
KPLMSII	1		13	2	0	7			23
KPLM	1	5	60	10	10	0	8	23	117
KRLM		1	9	5		9	0	1	25
LS	2	3	24	19	2	15	1	0	66
Col Tot	32	51	160	72	19	121	25	64	544

Transition Probability Matrix, Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS
SS	0.00	0.42	0.39	0.03	0.00	0.09	0.00	0.06
Slst	0.25	0.00	0.27	0.13	0.00	0.13	0.02	0.21
MS	0.09	0.12	0.00	0.18	0.04	0.44	0.03	0.09
Mic	0.01	0.12	0.38	0.00	0.01	0.16	0.14	0.18
KPLMSII	0.04	0.00	0.57	0.09	0.00	0.30	0.00	0.00
KPLM	0.01	0.04	0.51	0.09	0.09	0.00	0.07	0.20
KRLM	0.00	0.04	0.36	0.20	0.00	0.36	0.00	0.04
LS	0.03	0.05	0.36	0.29	0.03	0.23	0.02	0.00

Independent Trials Probab. Matrix, Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS	
SS	0.00	0.10	0.31	0.14	0.04	0.24	0.05	0.13	1.00
Slst	0.06	0.00	0.32	0.15	0.04	0.24	0.05	0.13	0.99
MS	0.08	0.13	0.00	0.19	0.05	0.31	0.06	0.17	0.99
Mic	0.07	0.11	0.34	0.00	0.04	0.26	0.05	0.14	1.00
KPLMSII	0.06	0.10	0.31	0.14	0.00	0.23	0.05	0.12	1.01
KPLM	0.07	0.12	0.37	0.17	0.04	0.00	0.06	0.15	0.99
KRLM	0.06	0.10	0.31	0.14	0.04	0.23	0.00	0.12	1.00
LS	0.07	0.11	0.33	0.15	0.04	0.25	0.05	0.00	1.00

Difference Matrix, Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS
SS	0.00	0.32	0.08	-0.11	-0.04	-0.15	-0.0489	-0.06
Slst	0.19	0.00	-0.05	-0.02	-0.04	-0.12	-0.03	0.08
MS	0.01	-0.01	0.00	0.00	-0.01	0.12	-0.03	-0.07
Mic	-0.05	0.01	0.04	0.00	-0.03	-0.10	0.08	0.04
KPLMSII	-0.02	-0.10	0.26	-0.05	0.00	0.07	-0.05	-0.12
KPLM	-0.07	-0.08	0.14	-0.08	0.04	0.00	0.01	0.05
KRLM	-0.06	-0.06	0.05	0.06	-0.04	0.13	0.00	-0.08
LS	-0.04	-0.06	0.03	0.14	-0.01	-0.03	-0.04	0.00

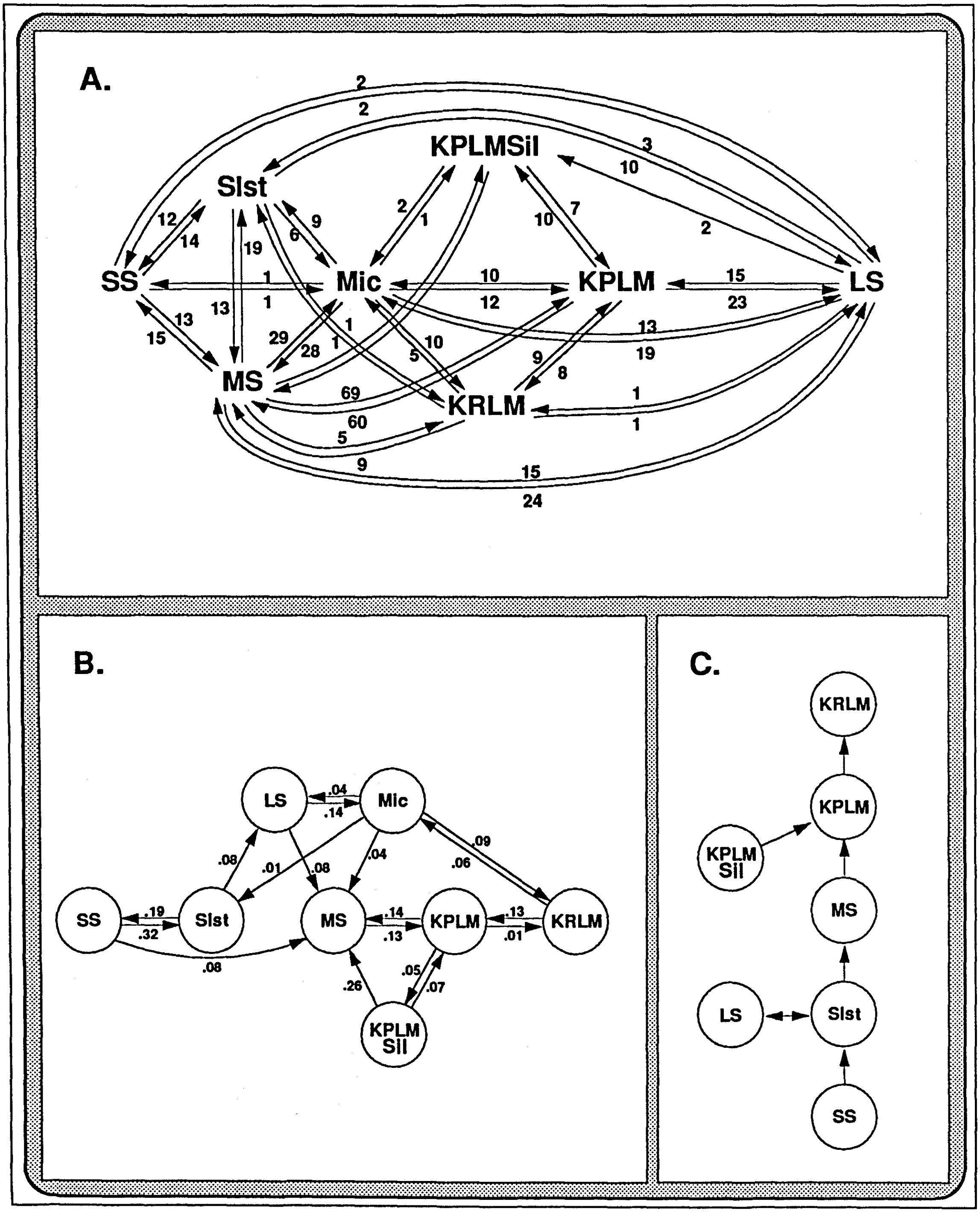


Figure 11. Facies relationship diagrams (FRD) for sections in the northern group: FB, FR, CC, BD, ChC, AR, based on data from Table 3. A. FRD showing the observed number of transitions between lithofacies. B. Revised relationships based on transitions which occur more commonly than random. C. Simplified FRD derived from interpretation of A and B.

Table 4
Tabulation of facies relationships using Markov Chain Analysis (Embedded), Southern Localities: CaC, ShC, S/LMC, HC (Analysis of individual localities are found in Appendix 4)

Transition Count Matrix — Lower Bed (rows) / Upper Bed (columns)

Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS	Row Tot
SS	0	45							45
Slst	45	0	6	8	1	2		32	94
MS		2	0	1		17		1	21
Mic		8		0		4		1	13
KPLMSII		1			0	3			4
KPLM		7		1		0	3	1	12
KRLM		1		1		2	0		4
LS		33						0	33
Col Tot	45	97	6	11	1	28	3	35	226

Transition Probability Matrix — Lower Bed

Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS
SS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Slst	0.48	0.00	0.06	0.09	0.01	0.02	0.00	0.34
MS	0.00	0.10	0.00	0.05	0.00	0.81	0.00	0.05
Mic	0.00	0.62	0.00	0.00	0.00	0.31	0.00	0.08
KPLMSil	0.00	0.25	0.00	0.00	0.00	0.75	0.00	0.00
KPLM	0.00	0.58	0.00	0.08	0.00	0.00	0.25	0.08
KRLM	0.00	0.25	0.00	0.25	0.00	0.50	0.00	0.00
LS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00

Independent Trials Probab. Matrix — Lower Bed

Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS	
SS	0.00	0.54	0.03	0.06	0.01	0.15	0.02	0.19	1.00
Slst	0.34	0.00	0.05	0.08	0.01	0.21	0.02	0.27	0.98
MS	0.22	0.47	0.00	0.05	0.00	0.14	0.01	0.17	1.06
Mic	0.21	0.46	0.03	0.00	0.00	0.13	0.01	0.16	1.00
KPLMSil	0.20	0.44	0.03	0.05	0.00	0.13	0.01	0.16	1.02
KPLM	0.21	0.45	0.03	0.05	0.00	0.00	0.01	0.16	0.91
KRLM	0.20	0.44	0.03	0.05	0.00	0.13	0.00	0.16	1.01
LS	0.23	0.50	0.03	0.06	0.01	0.15	0.02	0.00	1.00

Difference Matrix — Lower Bed

Lower Bed	SS	Slst	MS	Mic	KPLMSII	KPLM	KRLM	LS
SS	0.00	0.46	-0.03	-0.06	-0.01	-0.15	-0.02	-0.19
Slst	0.14	0.00	0.01	0.01	0.00	-0.19	-0.02	0.07
MS	-0.22	-0.37	0.00	0.00	0.00	0.67	-0.01	-0.12
Mic	-0.21	0.16	-0.03	0.00	0.00	0.18	-0.01	-0.08
KPLMSil	-0.20	-0.19	-0.03	-0.05	0.00	0.62	-0.01	-0.16
KPLM	-0.21	0.13	-0.03	0.03	0.00	0.00	0.24	-0.08
KRLM	-0.20	-0.19	-0.03	0.20	0.00	0.37	0.00	-0.16
LS	-0.23	0.50	-0.03	-0.06	-0.01	-0.15	-0.02	0.00

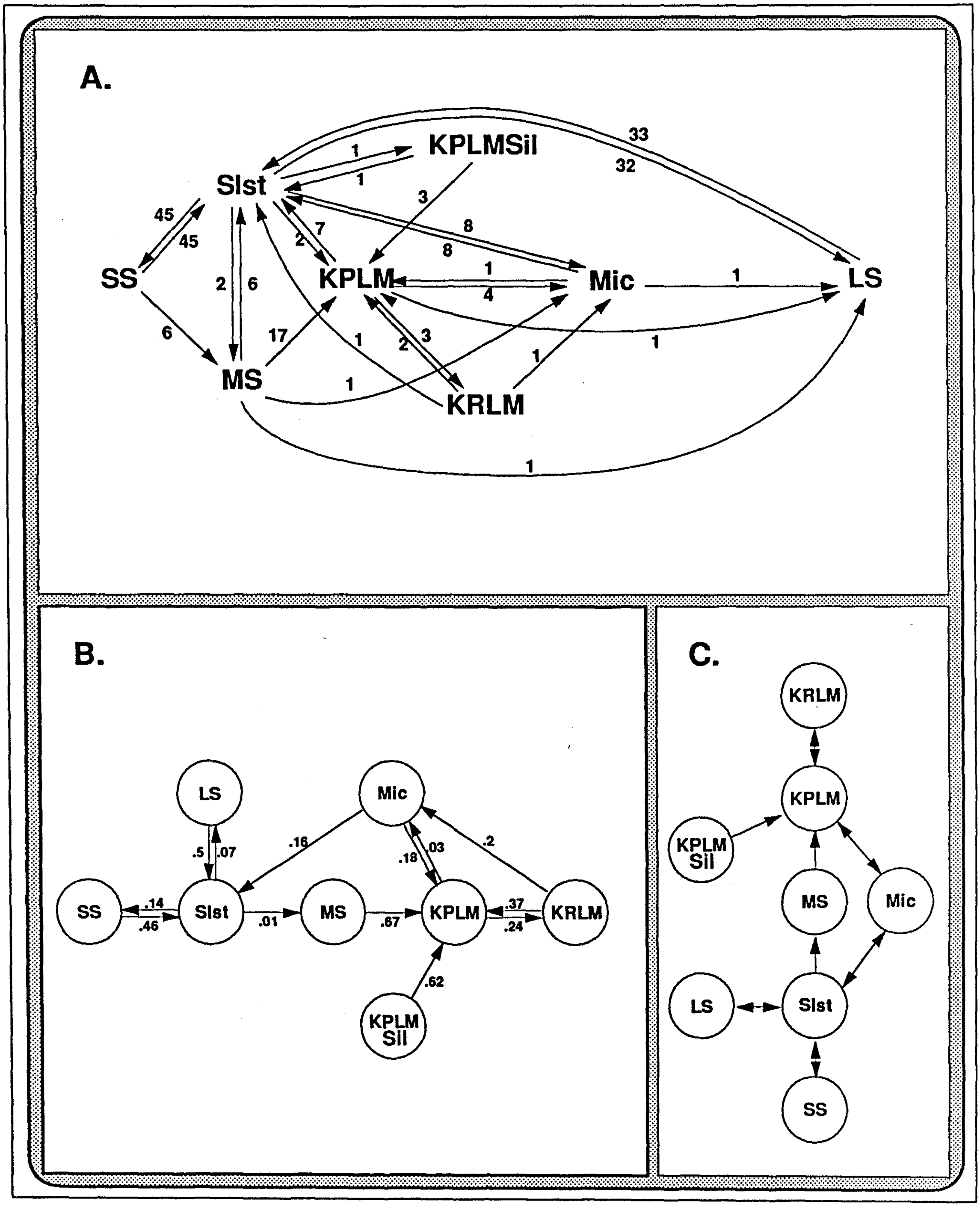


Figure 12. Facies relationship diagrams (FRD) for sections in the southern group: CaC, ShC, S/LMC, HC, based on data from Table 4. A. FRD showing the observed number of transitions between lithofacies. B. Revised relationships based on transitions which occur more commonly than random. C. Simplified FRD derived from interpretation of A and B.

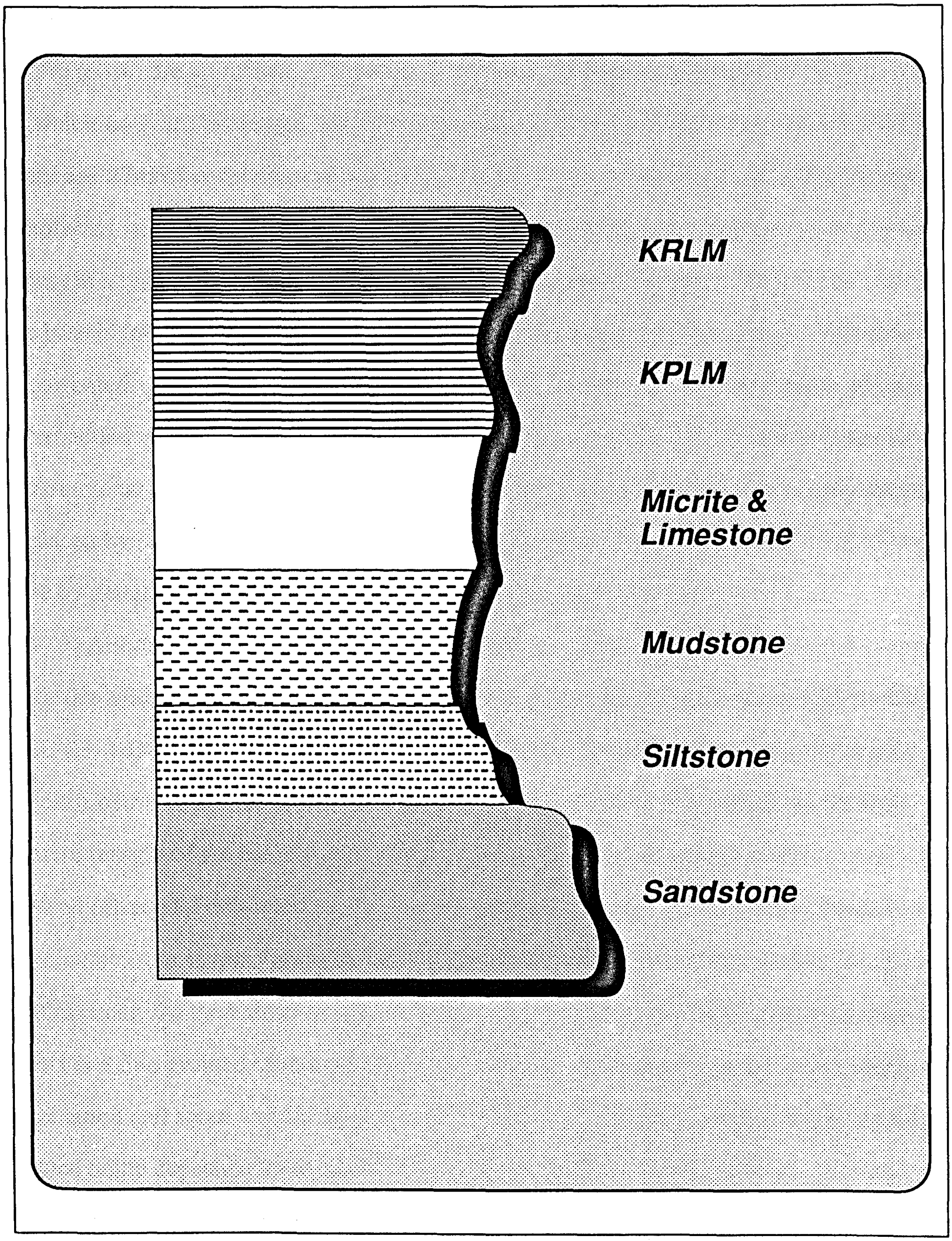


Figure 13. Lower Unit lithofacies assemblage showing the vertical preferred transition of lithofacies.

at BD locality is the thickest occurrence of total carbonate sediments (54.5m) of which 34.4m (63%) are laminated. To the north at Clear Creek (CC) 22.6m of carbonates occur of which 64% are laminated and where some of the richest oil shales are found. At ChC there are 27m of carbonates of which 36% are laminated. At these localities carbonate lithofacies succession occurs in the cyclic sequence shown in the lithofacies assemblage where in a typical regressive sequence succeed each other as follows: KRLM (oil shale) at the base is followed by KPLM, in turn succeeded by micrite which in many of the cases is bioturbated. Towards the top of these sections limestone units are more abundant interbedded with siltstones. In general the carbonates become diluted towards the top of the sections (as well as from basin center towards the margins), where they become replaced by siliciclastics of the Sandstone Tongue of the Wasatch Formation represented here by deltaic sandstones, siltstones and limestones which cap the Lower Unit.

Although the Lower Unit reflects a paucity of dolomite deposits, a major contrast with the Middle and Upper Units, some isolated dolomicrite beds occur such as CC-1, ChC-48, BD-15A2 and C, as well as some slightly dolomitic (lithology dominated by calcite) ostracodal limestones and laminated calcimicrites. Nevertheless, towards the eastern margin of the basin at AR locality is a sequence which contains little oil shale, but instead ostracodal dolomicrites. In the AR section (at the Eastern margin of Fossil Lake), where dolomite is most abundant especially in the lower half of the section, interesting cycles occur. At the base of the Lower Unit, just above the Wasatch Formation contact unit AR-1 is a fine-grained sandstone containing dolomitic intraclasts and exhibiting lenticular lamination and scour and fill structures. This is followed by laminated dolomicrite with a graded oolite deposited on an unconformable surface. Dolomicrite continues until replaced by a much thicker laminated pelmicrite with coprolites and some burrows (AR-3). This cycle or package is repeated by AR-4B-C. Unit 4B is an ostracodal dolomicrite with burrows. It is succeeded by bedded calcimicrite that is heavily burrowed. AR-5 appears to be part of this sequence but is a siliciclastic mudstone with burrows, and abundant mudstone casts of gastropods. The third cycle repeats the same package of lithotypes (AR-6-9). The basal carbonate unit exhibits mudcracks and the scour and fill structures indicate higher energy conditions. The section (after several similar cycles) is capped by the Sandstone Tongue of the Wasatch Formation which exhibits typical deltaic characteristics (Figure 5D).

Buchheim and Eugster (1989, in preparation) report significant beds of dolomite in the uppermost part of the Middle Unit where a well developed "ostracodal dolostone" constitutes an easily correlated bed throughout the basin, and a greater abundance in the Upper Unit where dolomite is dominant in the form of dolomicrites and associated with an abundance of saline minerals.

Cyclicity is also evident in some well developed sequences of alternating KPLM and organic rich mudstones (some with abundant plant fragments). Such is the case at BD, where at the base of the section there is a sequence about 8m thick of alternating mudstone (massive to laminated) and laminated micrite (BD:12-16). Several cycles occur (at least 6 in one 5.3m sequence), which indicates rapidly changing depositional conditions. Most of the micrites contain abundant fossils (plant remains, ostracodes and fish), and some individual beds become quite organic rich qualifying as oil shales. Another interesting similar cyclic sequence can be found at the bottom of the ChC section where mudstones and alternating laminated micrites (ChC-25) form a brown band of slope forming sediments of approximately 3.4m.

In the southern part of Fossil Basin sections become increasingly siliciclastic, and eventually are replaced by the Wasatch Formation in the vicinity of Hill Creek (Figure 5F). Although total thicknesses of sections are comparable to other sections to the north, carbonates are dramatically diluted, of which the majority are limestones, with only a few and very thin laminated micrites present. At ShC (Figure 5E) a few thin (ca. 30cm) KPLM occur, some of which contain abundant insects and plant fragments, with one KPLM unit containing a thin and slightly developed oil shale. This is the southernmost occurrence of oil shale in Fossil Basin. At the southernmost locality studied, HC, the general lithofacies relationships are dominated by alternating siltstones and limestones with only one thin occurrence of KPLM containing ostracodes.

In the northern part of the basin from Fossil Butte northward the Lower Unit thins rapidly and is replaced by the Wasatch Formation. At FB the section is characterized by an abundance of bioturbated micrite interbedded with laminated micrite and capped by a 4m sequence of siliciclastic mudstone and laminated micrites. Further north total thicknesses decrease markedly (to 10m) and are characterized by bioturbated sediments and only a few thin beds of laminated micrite. At northernmost locality 17 (Figure 5B) the Sandstone Tongue of the Wasatch Formation could be represented by a 4m unit of green silty sandstone.

Tuffs are present in the Lower Unit sediments, but are not nearly as abundant as in the Middle and Upper Units. No tuffs were found in the Southern portion of Fossil Basin, although very thin tuffs altered to clays may have been masked within mudstone units. Tuffs found at ChC, CC, FR are typically analcimic and at FB tuffs are analcimic lower in the section and contain analcime and authigenic K-spar in the upper portion of the section. The presence of analcime indicates a more saline and alkaline environment, and towards the top and the Middle Unit the formation of K-spar indicates a much more alkaline environment since K-spar forms in areas with pH>9 (Surdam and Parker, 1972).

In summary an idealized distribution of lithologic facies both laterally and vertically is presented in figure 14.

The cyclicity and vertical variability of the lithologic facies is a good indication of the dynamic nature of Fossil Lake. At high stands of the lake environment (transgression) oil shales and KPLM reach their largest areal extents, with ostracodal and gastropodal

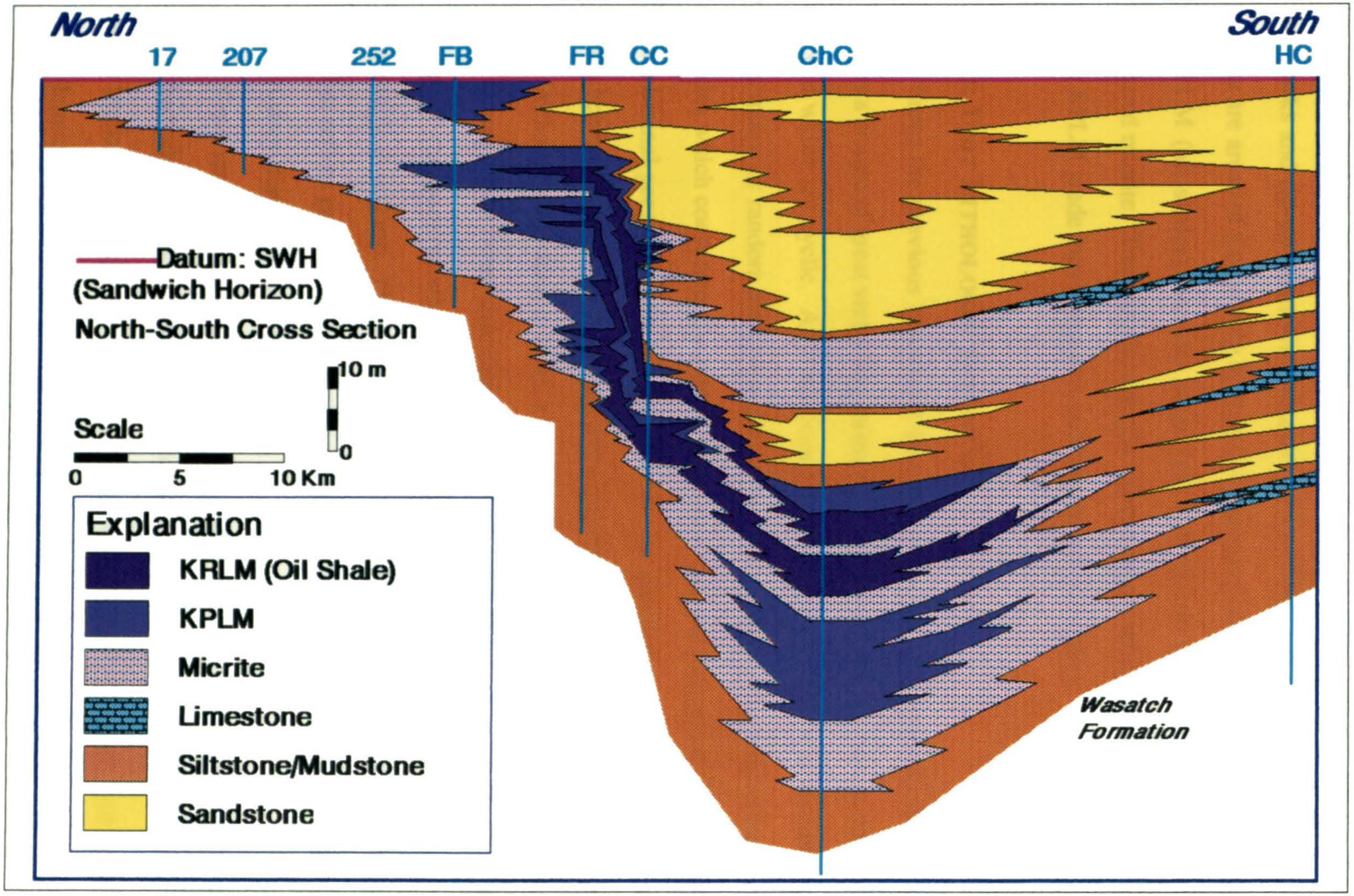


Figure 14. North-south cross section illustrating the vertical and lateral lithofacies relationships of the Lower Unit, Fossil Butte Member, Green River Formation in Fossil Basin.

limestones forming at the margins. At the eastern margins (AR locality) dolomicrites, mudcracks and rip-up clasts are indicative of mudflat environment, while southwestern margins are areas of a relatively high rate of sediment influx. From the basin depocenter the KRLM (oil shales) laterally grade into KPLM and successively into micrite and bioturbated micrite. Towards the margins micrites grade into siliciclastics. In the norther regions KPLM grade into limestones and bioturbated limestones.

LOWER UNIT LITHOLOGIC SUBUNITS

From the previous lithofacies analysis of the outcrops studied in Fossil Basin emerges a picture of great variability, as demonstrated by minute (in the cm scale) changes, many of which are cyclic. As it has been demonstrated, much of this variability, which reflects minor or random environmental fluctuations, disguises a limited range of basic lithofacies which constitutes the lithofacies assemblage and succession. When considered from a basinal perspective these lithofacies can be grouped into lithologic subunits and allow a better understanding of vertical and lateral relationships throughout the basin.

Although deposition in Fossil Lake was essentially of a cyclic siliciclastic/carbonate nature throughout Lower Unit time, major distinctive lithofacies subunits (i.e. a major portion of the section which is dominated by one or two lithofacies) are readily recognizable in outcrop. These major subunits not only allow better correlation through the basin, but reflect general environmental trends which help in better understanding Fossil Lake's history during Lower Unit time.

From the bottom of the Lower Unit upwards four major lithologic subunits can be established which are (Figure.15): 1) a lowermost 'Lower Shale' subunit, followed by 2) a 'White Marker' subunit, followed by an 3) 'Upper Limestone' subunit, and capped by a major deltaic sequence, the 4) 'Sandstone' subunit (Sandstone Tongue of the Wasatch Formation). Figure 16 illustrates how two sections (CC and LMC) are subdivided in the

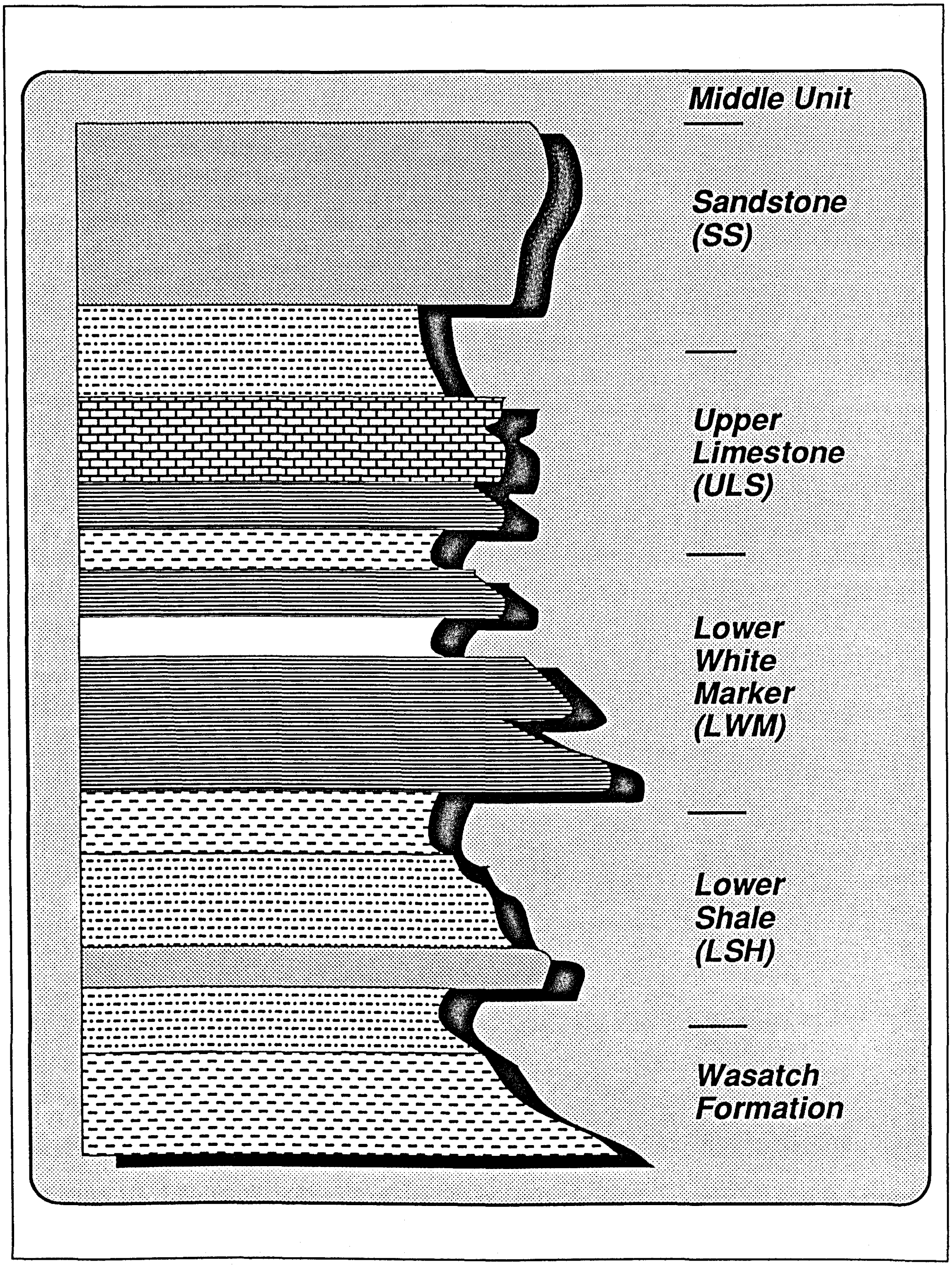
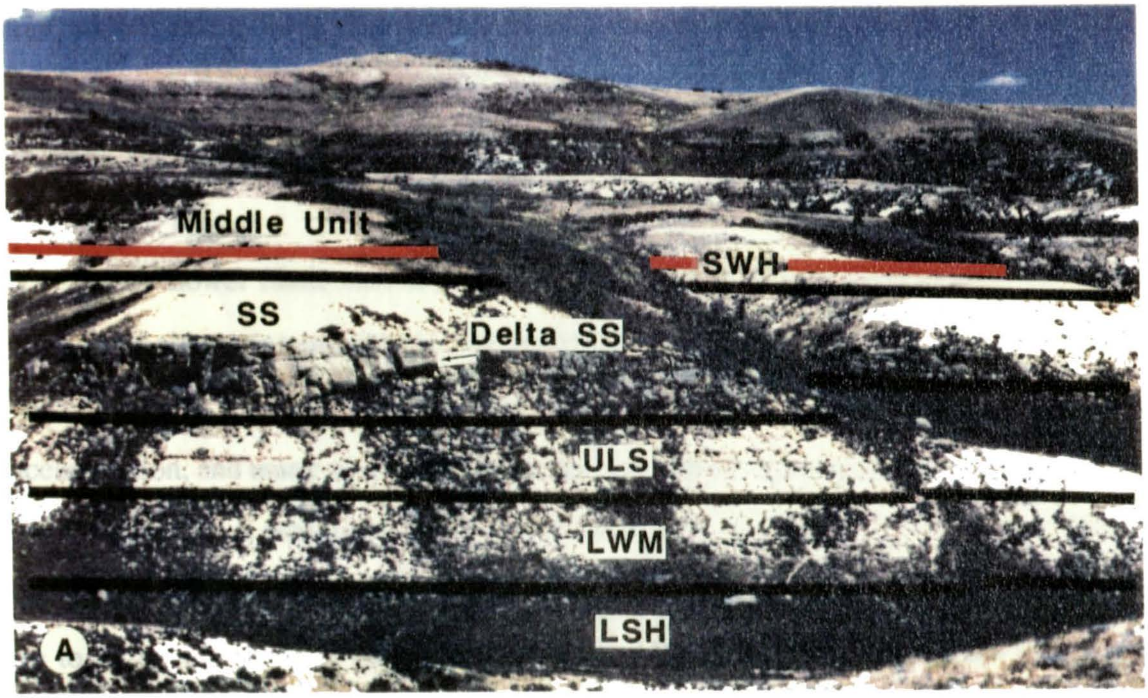


Figure 15. Major lithologic subunits in the Lower Unit, Fossil Butte Member



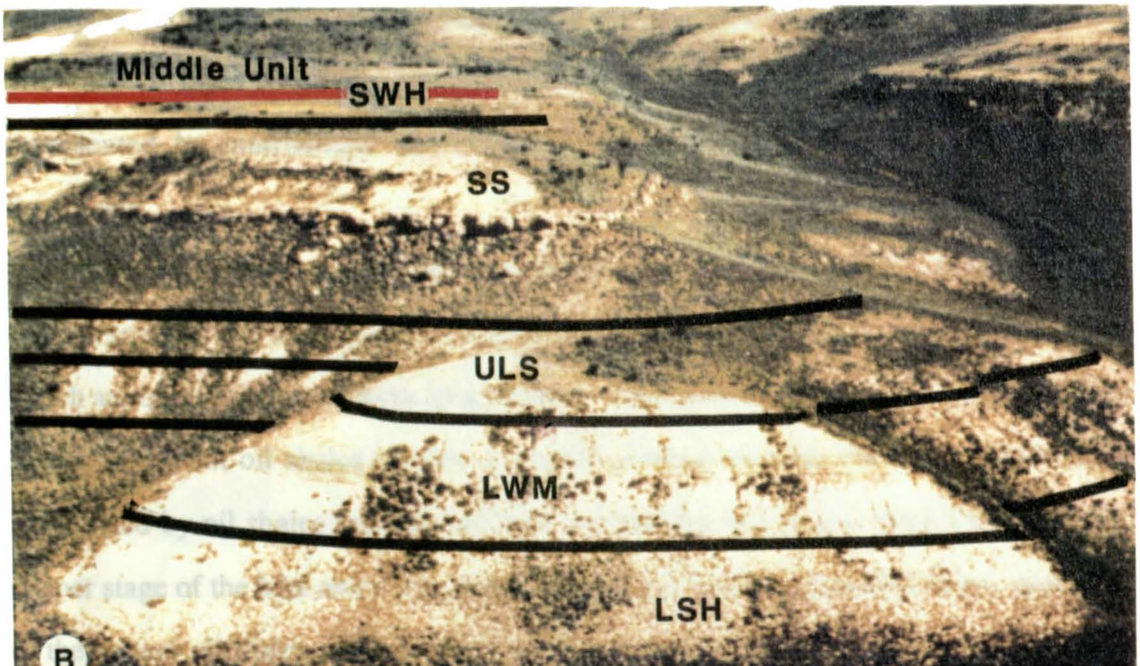


Figure 16. Lithologic subunits of the Lower Unit. A. Clear Creek (CC) and B. Lower Muddy Creek (LMC). Subunits are from bottom to top: Lower Shale (LSH), Lower White Marker (LWM), Upper Limestone (ULS), and Sandstone (SS). The Sandwich Horizon (SWH) in the Middle Unit, an extensive marker unit, was used as time unit for correlation.

four major subunits of the Lower Unit. These subunits facilitated correlation of sections through the basin which are presented in a north to south transect, and two west-east cross sections, one in the central part of the basin and the second one in the southern region (Figures 17-19).

The Lower Shale subunit is characterized by its brown-greenish-gray color and consists of alternating mudstones, calcimicrites and siliceous calcimicrites. Towards the basin center (ChC, CC), organic content is higher and resulted in some oil shale accumulation, and many of the mudstone units are organic rich, many containing abundant plant fragments. A distinctive "brown layer" occurs at ChC and BD, close to the bottom of the section, which is formed by alternating mudstone and laminated calcimicrite, and where up to 12 cycles occur in only a few meters. Although organic rich (plant fragments, petroleum odor), amounts of siliciclastics prevented the otherwise deposition of oil shale in this "brown layer". In the southern region this subunit grades into siliciclastics, represented by interbedded sandstones, siltstones and mudstones with a few thin limestones.

Very noticeable in outcrop is the White Marker subunit where a distinctive white color dominates this section due to weathering of oil shales and calcimicrites, the many of which are quite chalky and form long benches. This is the most attractive subunit because of the prominent oil shales present in several sections towards the center of the basin. Dominated by oil shales and calcimicrites interbedded with a few siliciclastics denote a deeper stage of the lake and correspond to major transgressions which allowed deposition of the thinner oil shales as far south as ShC as well as to the otherwise marginal localities such as AR and BD. These oil shales which are richest at CC, appear almost black due to their high organic content and contain abundant fossils: fossil fish, ostracodes, insects, and plant remains being the most common.

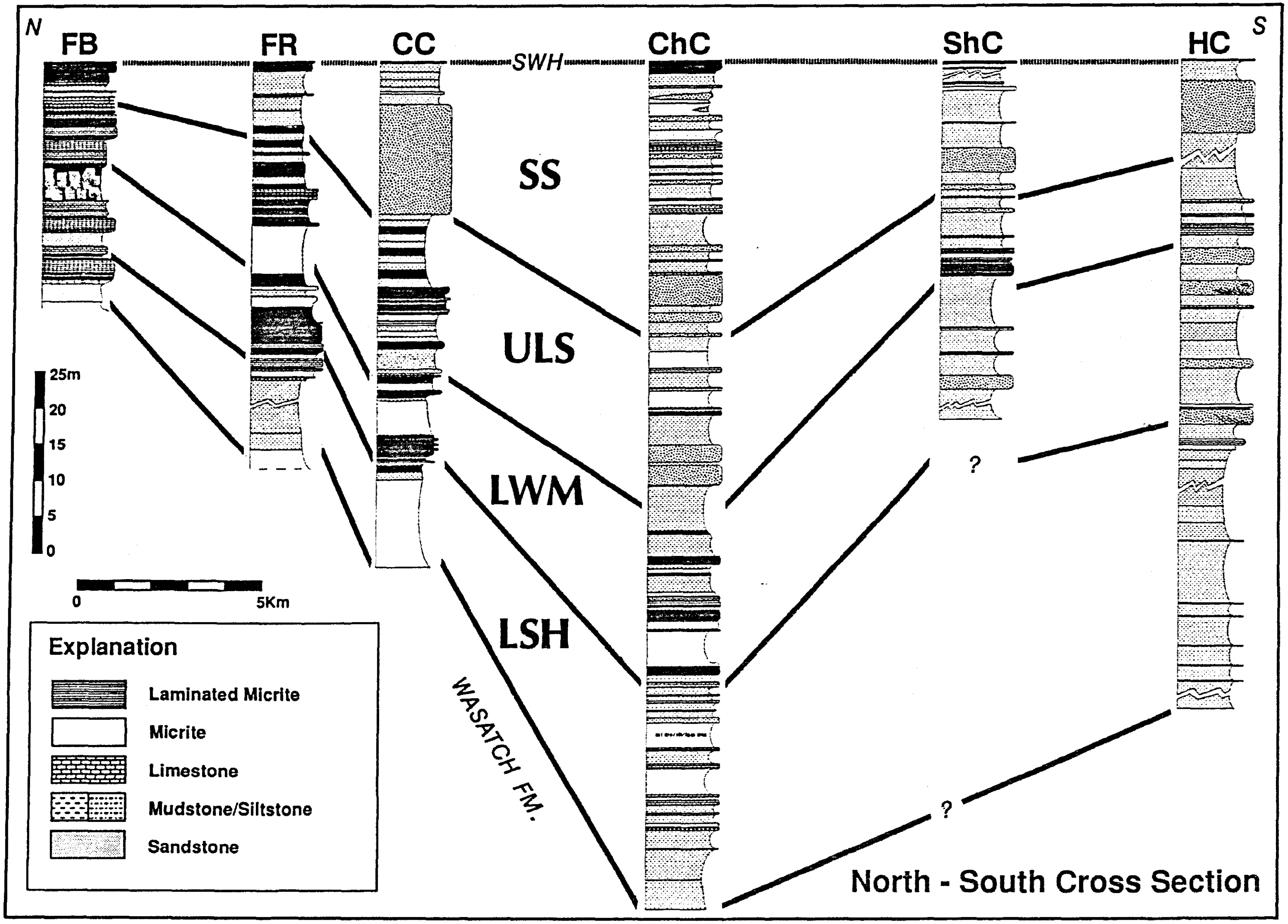


Figure 17. North-south cross section showing stratigraphic correlation of major subunits of the Lower Unit.

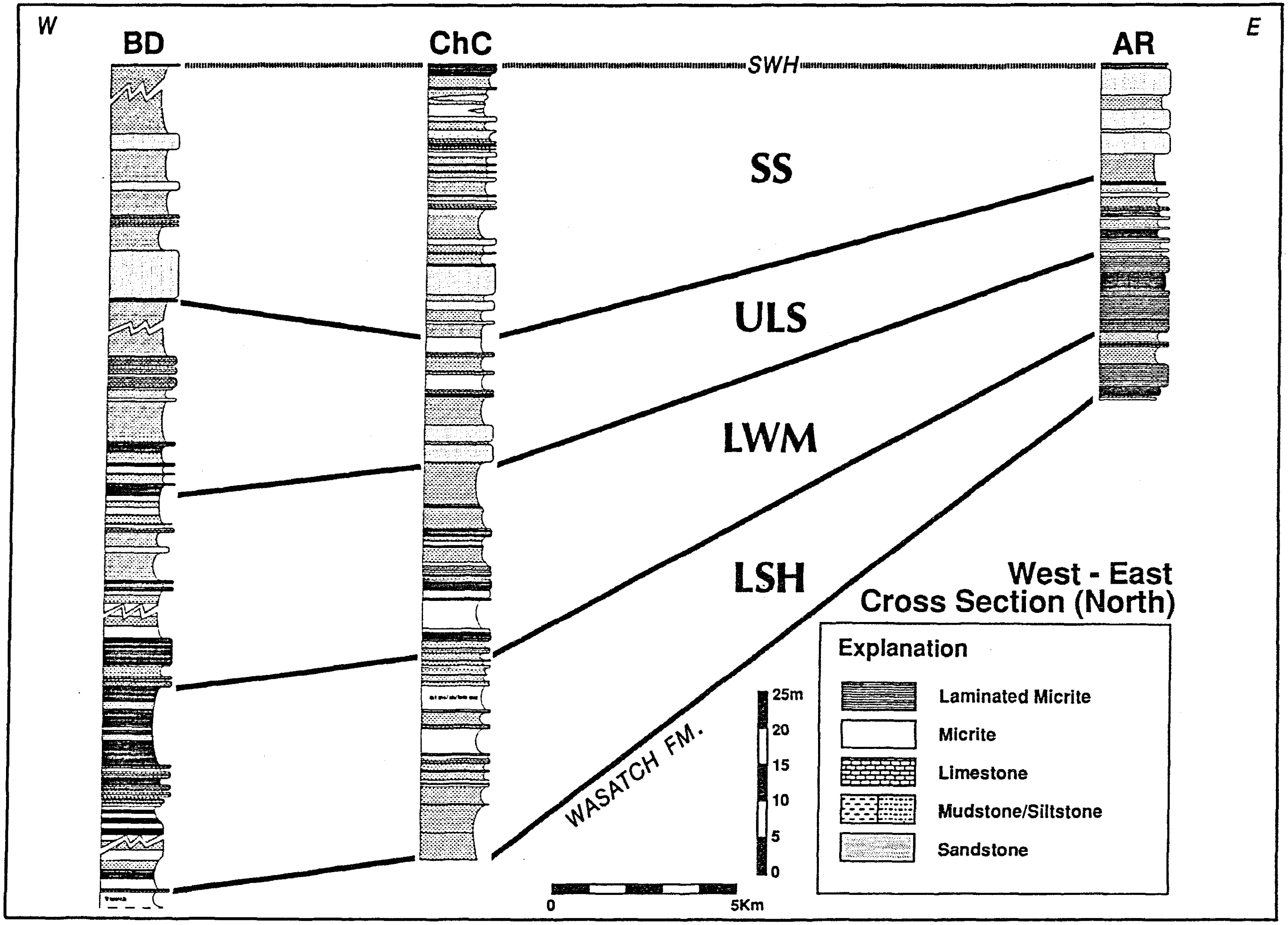


Figure 18. West-east cross section (north) showing stratigraphic correlation of major subunits of the Lower Unit.

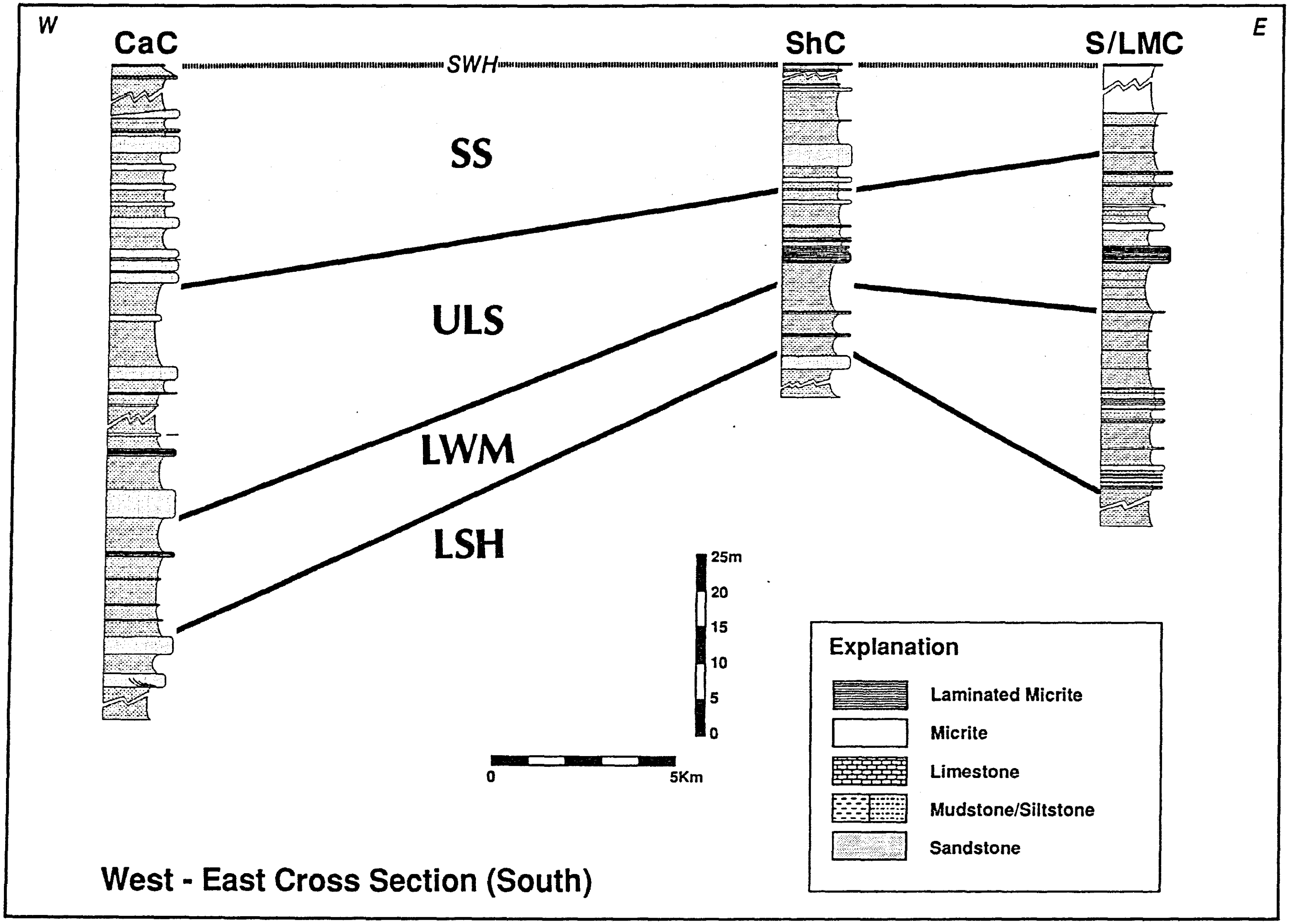


Figure 19. West-east cross section (south) showing stratigraphic correlation of major subunits of the Lower Unit.

The third subunit is the Upper Limestone characterized by its golden color. Here limestones alternate with siltstones and mudstones, with a unit of KRLM occurring at the bottom of the unit. Here abundant gastropods and ostracodes and in some localities pelecypods are typical in the limestones. This more littoral environment indicates a gradual infilling of the lake.

Major sandstone cliffs which dominate many of the upper portions of the ridges in the southern half of Fossil Basin and cap the Lower Unit, are part of the Sandstone subunit. This subunit is the Sandstone Tongue of the Wasatch Formation, and was studied in detail by Peterson (1987) who described it as being part of a Gilbert type delta which brought great influxes of siliciclastics from the S-SW into Fossil Lake.

PALEONTOLOGY-PALEOECOLOGY

Ever since the first surveys into the western territories a great abundance of fossils have been recovered from Fossil Basin, from the pre-Tertiary rocks surrounding the basin such as those of Oyster Ridge, to the lacustrine sediments deposited in Fossil Lake during the Eocene. Fossils of fish, plants, invertebrates and vertebrates are abundant in the rocks exposed in Fossil Basin, and have been studied in detail by Grande (1980). A brief summary of the paleontology of Fossil Basin was presented by McGrew and Casilliano (1975) as part of their geological history of Fossil Butte National Monument. These studies and most others have concentrated mostly on fossils obtained from the 'classic" fossil collecting units in Fossil Basin: the '18 inch layer' and the 'split fish layer' which most quarries have excavated. Both these layers are located in the Middle Unit of the Fossil Butte Member. Although the Lower Unit has not been as commercially attractive as the Middle Unit to fossil collectors, it also contains an abundant fossil flora and fauna.

The fossils found in this study are listed in Table 5 along with their known ecological preferences (actually of their modern day counterparts) and a few are pictured in

Table 5
List of fossils found in the Lower Unit, Fossil Butte Member, and their present ecological requirements

Vertebrates		Present Environments
Fish		
Lepisosteidae	*Lepisosteus*: gar	Shallow, weedy areas; swampy areas; streams, rivers.
Clupeidae:	*Knightia*: herring *Diplomystus*: herring-like	Very wide range, marine to non-marine.
Osteoglossidae	*Phareodus*	Rivers and lakes of S.America, Africa & Australia. Today 4 genera all freshwater tropical to subtropical.
Serronidae	*Priscacara*: sunfish	Breeds and nests in littoral zones
Turtles	Bones, carapace	Littoral environment
Crocodiles	Teeth	Nearshore
Birds	Bone-bed	Flamingo rookeries reported near FB.
Mammals	unident mammal jawbone	
Invertebrates		
Bivalves	*Unio*: clam	All molluscs found indicate freshwater conditions
Gastropods	*Goniobasis, Viviparus*	Association is consistent indicator of littoral lacustrine habitat; very shallow
	Physa, Omalodiscus	Association indicator of ponded-water habitat
Arthropods	Conchostracans: clam shrimp	Fresh and brackish water, shallow ephemeral ponds
	Ostracodes	Smooth shelled, typical of lakes
	Insects: unidentified specimens and larvae	
Trace Fossils	Burrows: unknown organisms	
Plants		
	Equisetum: horsetail *Typha*: cattail	Shallow, nearshore waters
	Unidentified leaf and stem fragments	
	Tufa coated logs	
	Flower	

figures 20-21. The fossil organism's ecological preferences are discussed later in relation to their paleoecological significance. Although identifiable specimens are relatively few this should not be taken as an indication of lack of variety, since taxonomic treatment of fossils was not in the scope of this study. For example, of 15 genera of fossil fish known from Fossil Basin, only five genera were identified from the Lower Unit in this study.

Total occurrence of fossil remains presented in Table 6 were tabulated in relation to the lithofacies in which they were found and also in relation to their stratigraphic occurrence in the Lower Unit. Fossil occurrence refers to the number of units of a lithofacies in which a particular fossil was found (i.e., of 38 KRLM units 12 contain articulated fish; 31.6% of all KRLM contain fossil articulated fish).

It is evident from the data in Table 6 that: 1) The greatest concentration of fossils occurs in the KPLM and KRLM lithofacies, as well as in the LWM and ULS Lower Unit subunits. As expected the most carbonate rich lithofacies and subunits are associated with the highest fossil content. 2) LS, also a carbonate, is not as fossil rich as the laminated carbonates but has a high content of fossils, and is followed by Micrite in fossiliferous content. 3) Significantly articulated fish are most abundant in the KRLM, followed by KPLM and LS. This indicates that the sedimentary conditions that deposited the laminated carbonates were favorable to the deposition and preservation of well articulated fish. It is also significant that of these lithofacies KRLM contains the highest amounts of well articulated fossil fish as well as scales and coprolites. This lithofacies also contains higher percentages of gastropods, ostracodes and other arthropods, as well as plant fragments. 4) It is also interesting that fish bones (disarticulated remains such as vertebrae, spines and skull fragments) occur in all lithofacies, while gastropods and ostracodes occur in all lithofacies except sandstone.

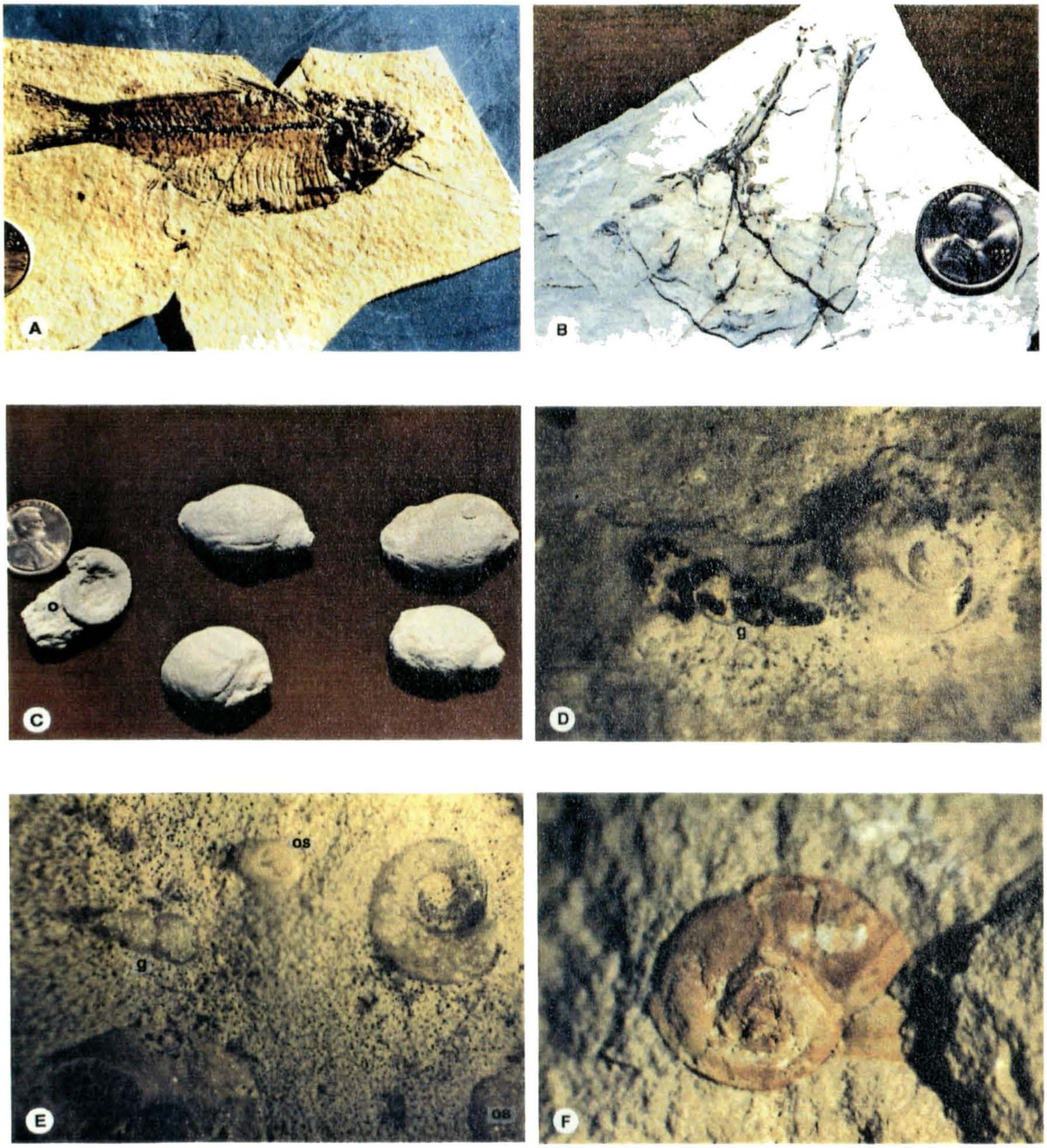


Figure 20. Fossils of the Lower Unit. A. *Knightia* (herring), photo courtesy of H.P. Buchheim. B. Vertebrate bones (possibly birds), ShC. C. Gastropods from CC and ShC include *Omalodiscus* (o) and more common *Physa*. D-F. Juvenile gastropods. D. *Goniobasis* (g), 2 mm in length, ShC-06. E. *Goniobasis* (g), 2 mm in length, with ostracodes (os) and other gastropod, ChC-28. F. Unidentified gastropod, 3 mm in diammeter, ShC-06.

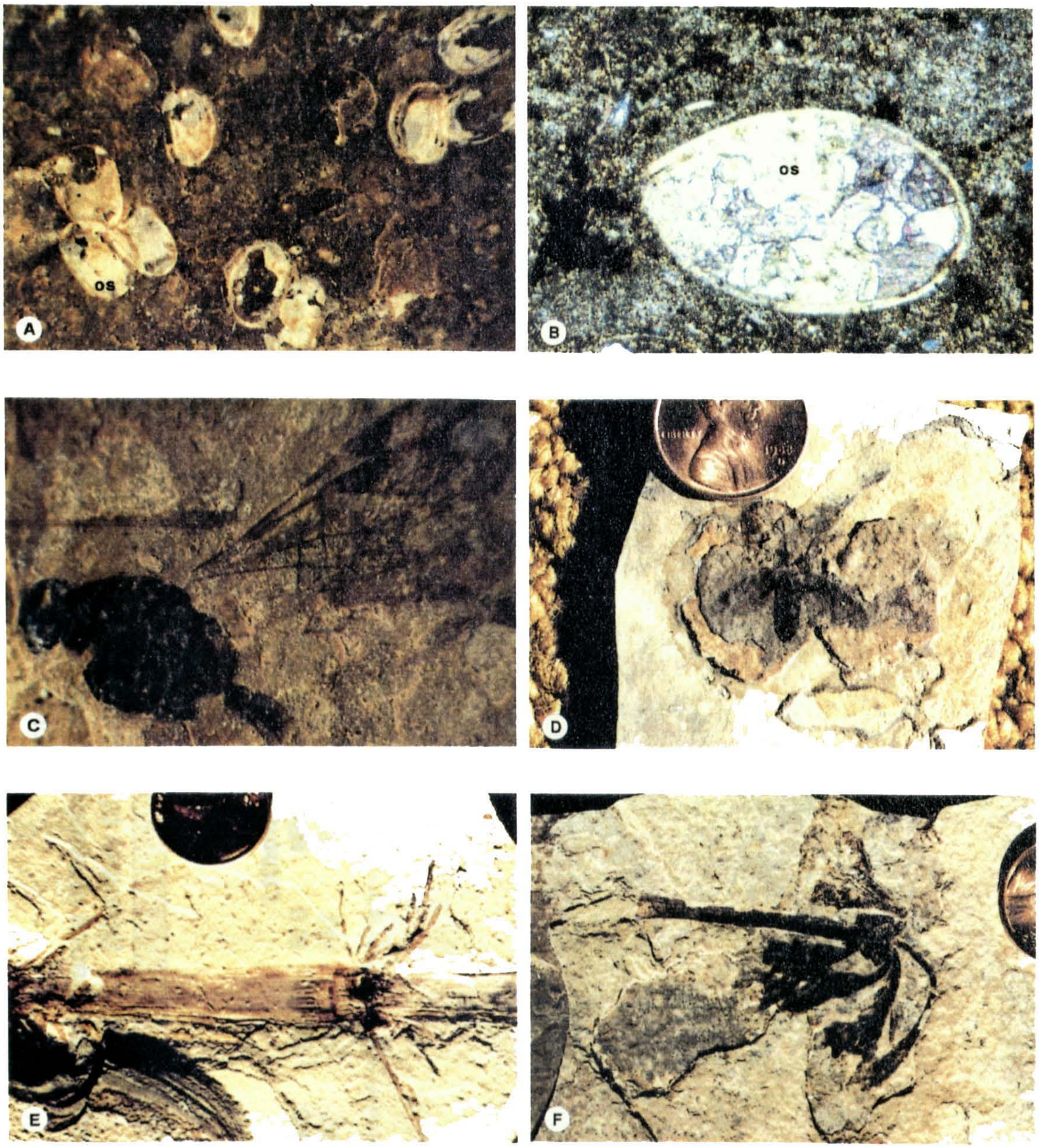


Figure 21. Fossils of the Lower Unit (continued). A-B. Ostracodes. A. Ostracodes (os) in laminae plane of a KRLM, length = 1.3 mm, CC-11. B. Ostracode (os) in thin section of an ostracodal limestone, length = 1 mm, HC-32. C-D. Insects. C. Length = 1 cm, CC-11. D. BD-48. E. *Equisetum* (horsetail), photo courtesy of H.P.Buchheim. F. Flower from CC-11.

Table 6
Total fossil occurrence in relation to lithofacies and stratigraphic position
(Number of occurrences/percent)

	Lithofacies							Lower Unit Subunits				
	SS	Slst	MS	Mic	KPLM	KRLM	LS	LSH	LWM	ULS	SS	Total
Total Lithologic Units	*82*	*133*	*152*	*69*	*120*	*38*	*128*					
Fossils												
Fish			1/.7		16/13.4	12/31.6	3/2.4	3	10	13	6	32
Fish Bones	1/1.2	1/.8	5/3.3	4/5.8	17/14.2	3/7.9	13/10.2	7	14	18	5	44
Fish Scales			2/1.3	1/1.5	6/5.0	5/13.2	2/1.6	3	6	7		16
Fish Copros					16/13.4	6/15.8	3/2.4	5	7	11	2	25
Other Vertebrates	1/1.2	1/.8			1/.9			1		1	1	3
Gastropods		2/1.5	2/1.3	1/1.5	3/2.5	3/7.9	10/7.8	4	6	6	5	21
Bivalves	1/1.2						3/2.4		1	1	2	4
Burrows		2/1.5	3/2.0	1/1.5	11/9.2		15/11.7	6	12	13	2	32
Ostracodes		1/.8	3/2.0	9/13.0	10/8.4	8/21.1	11/8.6	11	14	15	2	42
Conchostraca						1/2.7			1			1
Insects					4/3.4	4/10.6			4	4		8
Insect Larvae						2/5.3			2			2
Plant Fragments			3/2.0	1/1.5	5/4.2	4/10.6		4	4	4	1	13
Organic Fragments			3/2.0			1/2.7		1	1	2		4

DISCUSSION AND CONCLUSIONS

PALEOGEOGRAPHY-DEPOSITIONAL SETTING

1. Results from this study indicate an extensive and well developed lacustrine sequence for the Lower Unit in the southern half of Fossil Basin. Lower Unit sediments extend from Schuster Basin in the north to Hill Creek in the south, and from shoreline deposits at Oyster Ridge in the east to the well developed sequences at Bear Divide in the west. The best developed sequences during Lower Unit time are in the southern half of Fossil Basin, south of Fossil Butte. North of Fossil Butte Lower Unit sediments thin rapidly and it is in this area (at Fossil Butte) where the best developed Middle and Upper Unit sequences are present. This indicates a major location shift of the basin depositional center.

From the total thickness isopach map (Figure 22) it is apparent that Fossil Lake might have extended further west than Bear Divide. Faulting and erosion have produced an extensive topographical depression immediately West of the divide and there aren't any Fossil Butte Member sediments in the vicinity west of Bear Divide. But significant outcrops of primarily bioturbated micrite, stromatolites and oncolites occur ca.20 miles west which suggest shoreline conditions at this locality (Buchheim and Eugster, 1989 in preparation). Unfortunately correlation was not possible, and further study is needed to ascertain its relation to the Lower Unit present at Bear Divide. If these sediments are Lower Unit sediments, or even Middle Unit, Fossil Lake extended at some period of its existence much further west than presently recognized. This would be supported by the thick Lower Unit sequences found along Bear Divide.

2. Low topographic gradient of Fossil Basin. Buchheim and Eugster (1986) found that the relationship of the "K-spar tuff" to the Ostracodal dolostone, both in the Middle

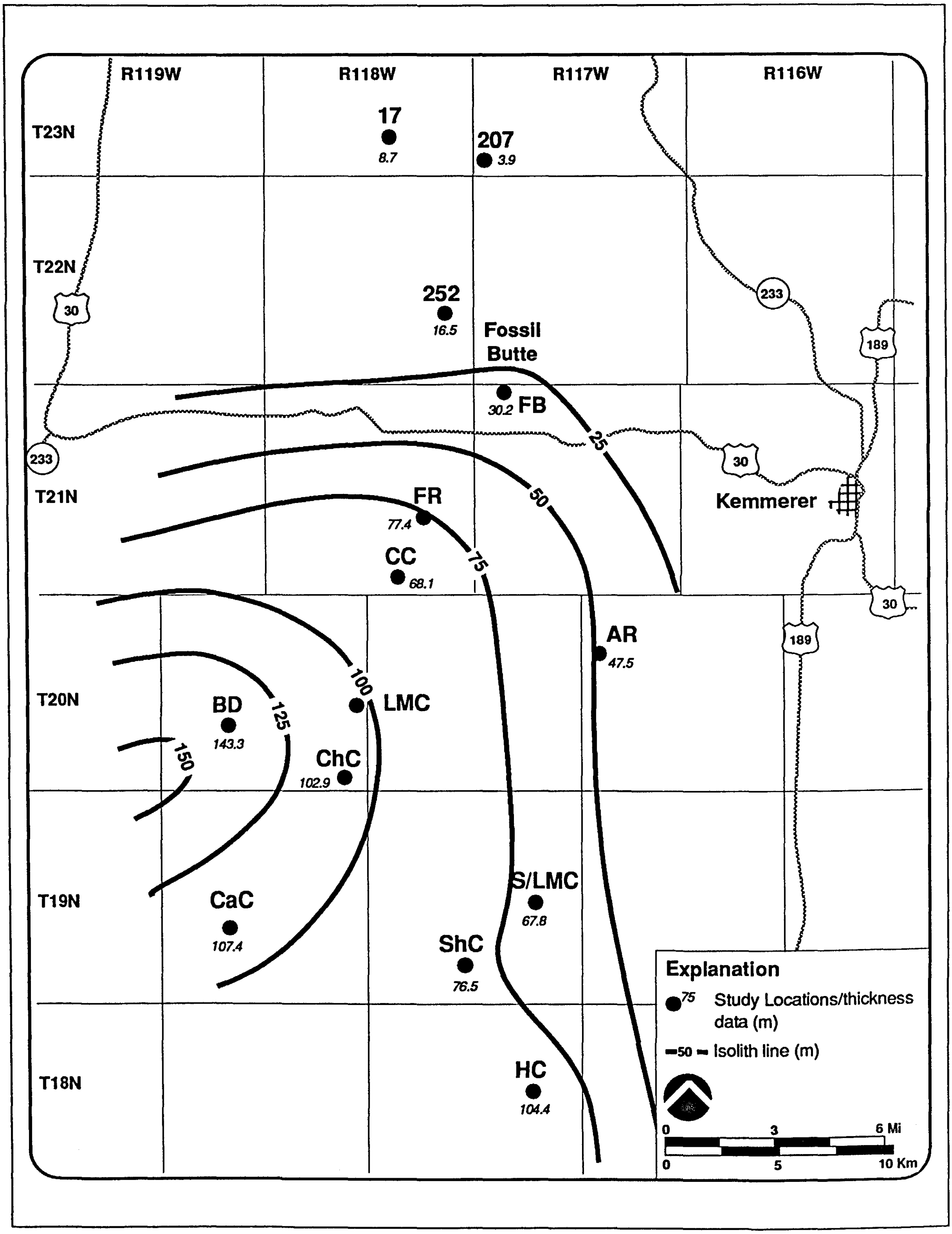


Figure 22. Isopach illustrating the total thickness of sediments of the Lower Unit, Fossil Butte Member.

Unit, provided a basin-wide time unit requiring shallow conditions. In addition they cited broad, shallow siliciclastic channels containing shallow-water features, interbedded with the oil shales, as well as associated evaporites and other shallow water features (mudcracks and lenticular laminae). In the Lower Unit there are similar relationships, especially the presence of ostracodes in the oil shales, and the lateral extent of some oil shales and sandstones.

3. Dynamic nature of Fossil Lake. The minute vertical lithofacies variability, as well as the organic and fossiliferous content and sedimentologic changes indicates a rapidly changing regime of depositional conditions.

PALEOENVIRONMENTS

After a century of studies, the Green River Formation rocks are considered one of the better known lacustrine sequences. Nevertheless, ever since Henderson (1924) posed the question of the origin of its oil shales (for which these deposits have become so economically important) and their relationship to the environment of deposition, there has been much controversy as to the depositional mode of these sediments, and the problem has not been satisfactorily resolved.

The controversy revolves primarily on the origin and depositional mode of oil shales (kerogen-rich laminated micrites) and their preservation along with an abundant variety of fossil fish, ostracodes, fossil plant remains and other vertebrates and invertebrates.

Several models have been proposed to account for the origin of these lacustrine sediments. Earlier studies of the Green River Formation by Bradley (1929, 1931, 1948, 1964), Picard (1955), Bradley and Eugster (1969), Piccard and High (1968), Smith and Robb (1973), Desborough and Pitman (1974), Roehler (1974), Smith (1974) Williamson and Piccard (1974), Desborough (1978), and Cole and Piccard (1978) led to the development of the "stratified lake model" which called for a large open drainage chemically and thermally stratified deep body of water.

In contrast, Eugster and Surdam (1973) proposed a closed-drainage "playa-lake" model. This model consisted of a shallow lake surrounded by a fringing mudflat, in which shallow water, low topographic gradient, transport of sediments on the mudflat and seasonal or periodic chemical stratification of lake water were its salient characteristics. This model found support in the work of Eugster and Hardie (1975), Smoot (1978) on the Wilkins Peak Member, Wolfbauer and Surdam (1974), Surdam and Stanley (1979a, 1980) on the Laney Member, and Surdam and Wolfbauer (1975) on the Tipton Shale Member, all in the Green River Basin. This model was also applied to Green River Formation sediments in other basins of Wyoming, Colorado and Utah by Lundell and Surdam (1975), Lundell (1977), Moussa (1976), Surdam and Stanley (1979b), Moncure and Surdam (1980).

Based on his studies of an Oligo-Miocene lacustrine sequence in North Dakota containing laminated carbonates and other lithologies and fossils of striking similarity with the Green River Formation sediments, Boyer (1981, 1982) proposed a third model in which a combination of the previous models would result in a closed basin ectogenic meromixis. In this model the lacustrine setting was continuously modified by external factors such as climatic changes, which produced lake fluctuations between a shallow playa and deeper meromictic conditions. In his study of subsurface sediments of the Wilkins Peak Member, Sullivan (1985) found that the interbeds of trona, oil shale, dolomitic mudstone and associated widespread fluvial clastic sequences of the Wasatch Formation are best explained by a combination of playa-lake and meromictic settings, thus supporting Boyer's (1982) model.

While most of these studies emphasized lithological and mineralogical aspects of the sediments, attempts to integrate the paleoecological information to paleoenvironmental interpretations are few. Although several studies have dealt with taxonomical aspects of Green River Formation fossils (for a review see Grande, 1980), and especially with fossil fish, comprehensive paleoecological studies are lacking. Baer (1969) discussed the paleoecology of fishes and associated invertebrates in his study of the lower Green River Formation in one locality of the Uinta Basin of Utah, and proposed an interdeltaic setting for the deposition of those sediments and organisms. Buchheim and Surdam (1981) found two major paleoenvironments and paleocommunities in their study of the fossil fishes and associated fossils of the Laney Member in the Green River Basin. This study of the relationships of fossil fishes to other fossils, sedimentology, stratigraphy and mineralogy, resulted in the recognition of two major paleoenvironments: the littoral (near-shore) and the limnetic (open-water), each with a characteristic paleocommunity and sedimentological features. In addition, with their studies of the occurrence of fossil catfish (Lundberg, 1975; Lundberg and Case, 1970; Buchheim and Surdam, 1977, 1984; Grande, 1980) support was found for the playa-lake model of Eugster and Surdam (1973) which allows oxygenated conditions throughout the lake, as well as temporary stratification.

From their studies in Fossil Basin McGrew (1975) and McGrew and Casilliano (1975) gave insights into the taphonomy and paleoecology of the fossil fishes there. Also in Fossil Basin Buchheim (1986) found that the relationship between fossil fish abundance, paleoecology, taphonomy, sedimentology and mineralogy is a key factor in determining depositional environments in Fossil Lake. In addition Cushman (1983) when he studied the Fossil Butte Member's palynoflora concluded that Fossil Lake was surrounded by moist lowlands and floodplains with upland forests on nearby ridges and mountains, and that vegetation is indicative of a transitional climate between humid-subtropical and a drier warm temperate with moderate fluctuations during the lifespan of the lake.

More recently Buchheim and Eugster (1986; 1989, in preparation) proposed a model for the depositional history of Fossil Lake in which from observations in the vertical and lateral distribution of kerogen-rich rocks and associated lithofacies, greater amount of sediment deposition towards the margins of the lake was the result of the dominance of inflow processes on deposition in the lake. They interpreted the sediments as having been deposited in a dynamic, shallow alkaline lake in a closed hydrographic basin. In their study they concluded that Fossil Lake began as a fresh and shallow water body in which productivity was very high supporting large numbers and varieties of fish. It gradually became more saline, evolving into a large, shallow hypersaline brine body in which evaporites precipitated as salt minerals producing an environment hostile to fish. By the end of Upper Unit time it freshened briefly and then ended its existence with the advent of fluvial environments.

Depositional Systems in the Lower Unit

The present study of the Lower Unit of the Fossil Butte Member in Fossil Basin, supports Buchheim and Eugster's (1986; 1989, in preparation) model. The overall character of the Lower Unit is one of freshwater lacustrine deposition punctuated frequently by siliciclastic input from surrounding fluviatile regimes. This inflow occurred throughout the time span of the Lower Unit but was greater at the beginning of Fossil Lake's history, during Lower Shale time, when a few sandstone beds were deposited, and then at the end of the Lower Unit time when fluviatile activity increased dramatically culminating in the development of a Gilbert-type delta bringing sediments into Fossil Lake from the southwest constituting the Sandstone Tongue of the Wasatch Formation. Siliciclastic deposition punctuated an otherwise tranquil lacustrine environment in which carbonate deposition was the norm, and where organic matter supported a rich and varied fauna (high productivity).

Carbonate deposition

In the Lower Unit of Fossil Basin carbonates are not as abundant as other carbonate deposits in the Green River Formation. There are no extensive and thick oil shale units as in the Middle Unit or as in the Green River Basin. But yet there are significant carbonate deposits in the Lower Unit and certainly much better developed than previously thought.

Carbonate was deposited in the Lower Unit in the form of micrites. These are almost entirely calcimicrites with only a few dolomicrite beds present. Calcitic deposition was the theme in the Lower Unit carbonates, with some beds of pure (90-95%) calcite to marls containing up to 50% siliciclastic material (quartz and feldspars), from massive micrites and limestones to fine laminated carbonate shales (KRLM and KPLM), are found predominantly in the Lower White Marker and Upper Limestone subunits (See Facies Associations). Although many of the limestones are biomicrites, such as ostracode and gastropodal limestones, and thus had a biogenic origin, the majority of the Lower Unit carbonates are the result of three other mechanisms: inorganic precipitation, bio-induced (by photosynthesis) carbonate precipitation, and allochthonous (detrital) influx of carbonate material from the surrounding drainage basin. These three mechanisms of carbonate formation were active during deposition of Lower Unit sediments as will be apparent from further discussion.

During Lower Unit time the majority of the carbonates being deposited were of a calcitic nature and very little dolomite deposition occurred. This seems to indicate that dolomite deposition represents isolated and localized depositional conditions which led to its formation.

In addition, the total carbonate and laminated carbonate thickness isopach map (Figure 23), shows a thicker carbonate concentration towards the western margin in the vicinity of the Bear Divide locality. Taking into account that the KRLM ("oil shale") are concentrated more centrally in the lake, near the Clear Creek (Figure 16A) and Fossil Ridge

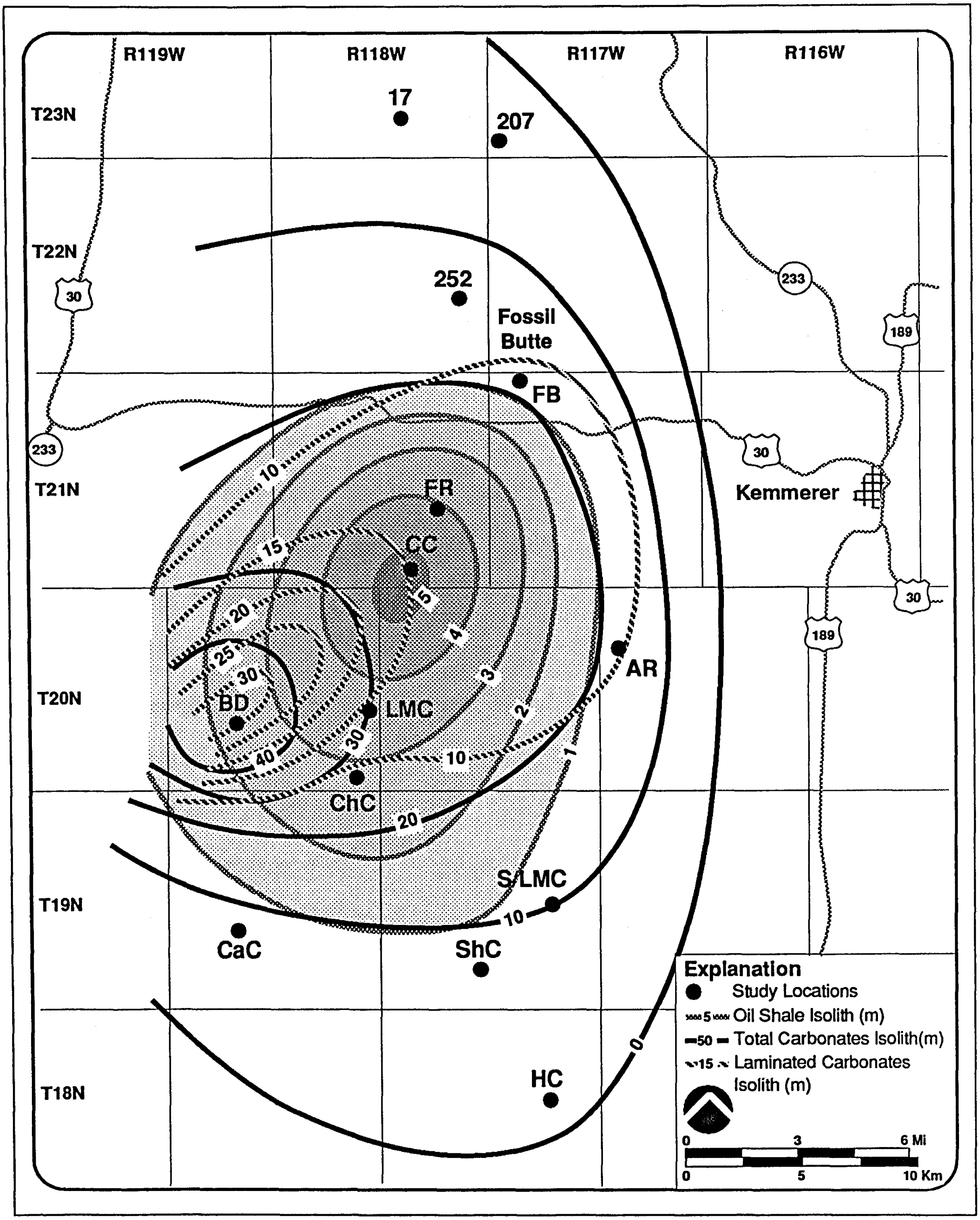


Figure 23. Isopach illustrating three types of carbonate distribution in the Lower Unit, Fossil Butte Member. Total carbonate thickness (solid lines), laminated carbonate thickness (hatched lines) and oil shale thickness (KRLM) (in the screened patterns).

(Figure 5C) localities (Figure 23) , and that the total section thickness isopach (Figure 22) and the siliciclastic/carbonate ratio isopach map (Figure 24) show a marked high towards the west and southwest respectively, it is suggested that greater siliciclastic influx from those areas was accompanied by calcium-rich waters which when mixing with the saline-alkaline waters of the lake resulted in a greater precipitation of calcium carbonate in those areas. This supports the conclusions of Buchheim and Eugster (1986).

Cyclicity is another of the salient characteristics of the sedimentary sequences in Fossil Basin. As described earlier, at the AR locality, several cycles of alternating siliciclastics/calcitic and dolomitic micrites denote rapidly changing depositional conditions. That these beds are associated with mudcracks (AR-6), lenticular lamination, and scour and fill structures is indication of shallow water, mudflat conditions conducive to dolomitization. Smoot (1978) found these conditions in the Wilkins Peak member of the Green River basin. The dolomitic dominance in these units has been associated with hypersaline conditions in the lake waters. These characteristics suggests rapid changes between subaerially exposed carbonate mudflat environments in which mudcracks developed and submerged lacustrine transgression stages, in addition to rapid influx of fluvial siliciclastics at these marginal localities.

KPLM are quite abundant in some carbonate sequences and also cyclic with organic rich (some with abundant plant fragments) mudstones. This is in agreement with the idea of periodic sheet floods bringing in plant remains and other organics from flood plains thus leading to an increase in productivity and precipitation of carbonates. In addition higher increased inflow probably resulted in higher precipitation of carbonates at the lake margins as the fresher calcium rich fluvial waters came in contact with more saline and alkaline waters of the lake. This increased carbonate precipitation at the margins resulted in dilution of organics in those areas.

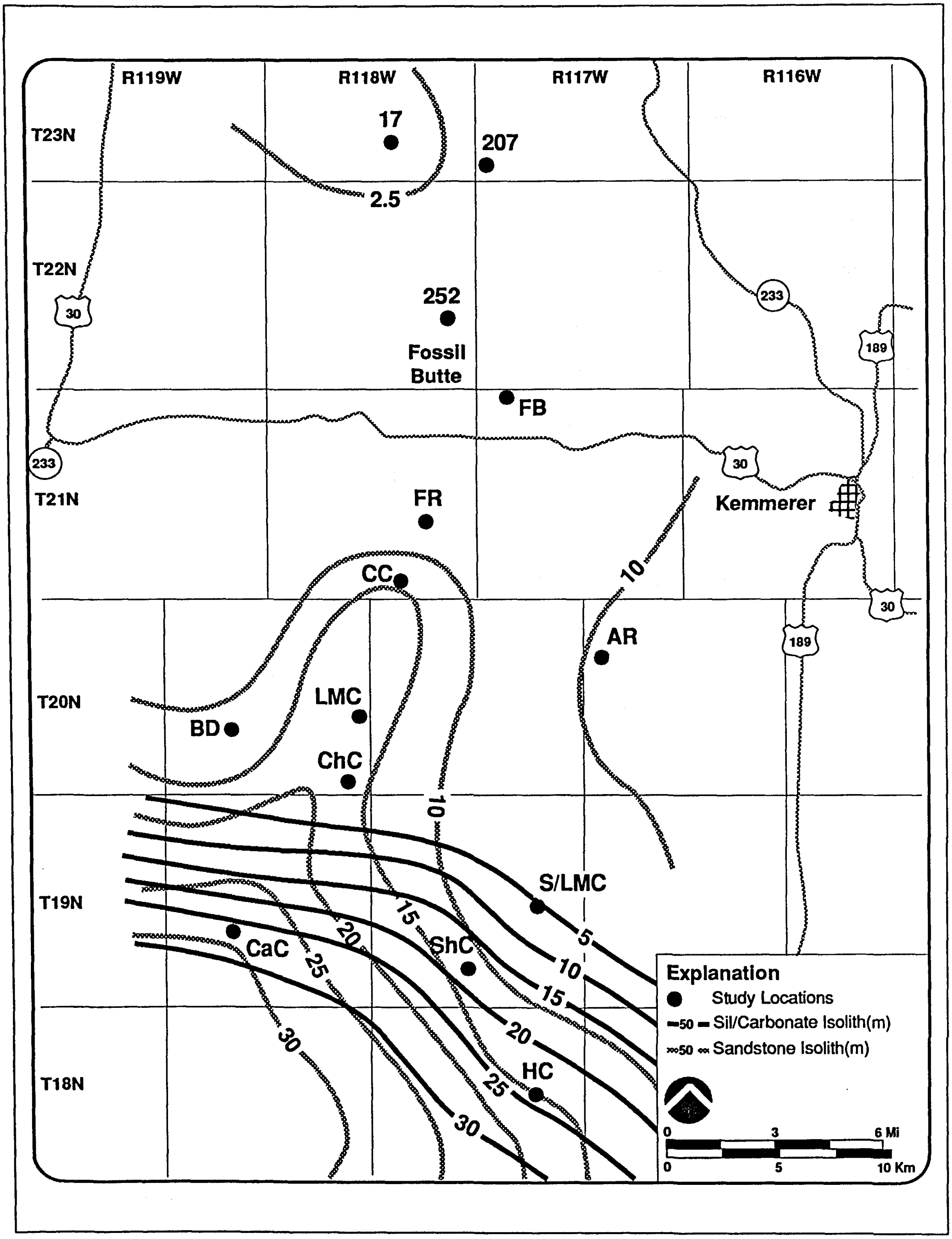


Figure 24. Isopach illustrating the siliciclastic/carbonate ratio (in the solid lines and sandstone thickness (screened lines) of the Lower Unit, Fossil Butte Member.

The vertical and lateral facies distribution:

From the basin depocenter KRLM laterally grade towards the margins into less organic rich but much thicker laminated carbonates (KPLM) and subsequently into bedded or massive micrites. This same gradation can be observed vertically and in addition carbonate facies successions are in intimate cyclic relationship with the siliciclastic facies. This facies change can be directly related to organic **dilution** towards the margins (as also suggested by Moncure and Surdam, 1980, Piceance Creek Basin; Sullivan, 1985, Wilkins Peak Member; Buchheim and Biaggi, 1988, Fossil Basin, and Buchheim and Eugster, 1989 in preparation, Fossil Basin). Mainly due to the influx of allochthonous carbonate and siliciclastics at the margins of the lake, sedimentation was greater at the marginal environments interrupting an otherwise continuous deposition of carbonate and organic matter. This accounts for the noted shoreward increase in laminae number as well as laminae thickness (Buchheim and Biaggi, 1988).

Also **bioturbation** appears as an important element in KPLM and increases in bioturbated micrites towards the margins away from the depocenter. Lack of bioturbation in the kerogen rich laminated sediments in the depocenter was attributed by Buchheim and Eugster (1989 in preparation) to reducing conditions within the sediment and at times at the sediment-water interface which discouraged bioturbators.

In addition, zeolite zonation from basin margin to depocenter as from the Lower to the Upper Unit, as indicated by the change in tuff bed mineralogy, which shows an analcime to potassium feldspar succession, suggest important **salinity** gradients: salinity increase from basin margin to depocenter and an overall increase in salinity from Lower to Upper Unit (Surdam and Sheppard, 1978; Buchheim and Eugster, 1989, in preparation). Salinity increase towards the basin depocenter probably played an important role in preventing the action of bioturbators.

LOWER UNIT DEPOSITIONAL MODEL:

The detailed stratigraphic and lithofacies analysis presented thus far, allows the formulation of a depositional model for the sediments of the Lower Unit. The model resembles those of Buchheim and Eugster (1989, in preparation) for Fossil Basin, and Ryder et al (1976) and Fouch and Dean (1983) for the Uinta Basin. The model is illustrated in figure 25, and shows the occurrence and distribution of four major depositional environments: (1) open-lacustrine,(2) marginal-lacustrine, (3) carbonate mudflat, and (4) fluvio-deltaic. Figure 25 represents the depositional settings in Fossil Lake at the end of Lower Unit time. The open-lacustrine facies developed in the central part of the lake to form an elongated (North to South) body of sediments which typically extend from Fossil Ridge to Chicken Creek. This facies is surrounded shoreward by the marginal-lacustrine facies. Towards the eastern margin (near the AR locality) conditions developed a localized carbonate mudflat facies which probably extended along that margin. The fluvio-deltaic facies is the dominant facies in the western-south-western and southern margins of Fossil Lake. Fluvial events dominate the southern margins throughout the life of the lake. While at the southwestern margin a major Gilbert-type delta at the end of Lower Unit time gradually covered most of the southern half of Fossil Lake with deltaic sandstones and related siliciclastics extending North up to Fossil Butte in the form of claystone.

Table 7 presents a summary of useful criteria which characterize each depositional facies. Criteria are divided into four categories: (1) lithofacies, (2) mineralogy, (3) sedimentary structures, and (4) paleontology.

The **open-lacustrine facies** is characterized by KRLM, KPLM, limestones with some fossils, and calcareous mudstones (claystone). The carbonates are dominated by calcite although some dolomicrite occurs. Fluvial events deposited siliciclastics into the open-lacustrine environment in the form of thin sandstone beds and siltstones. The KRLM

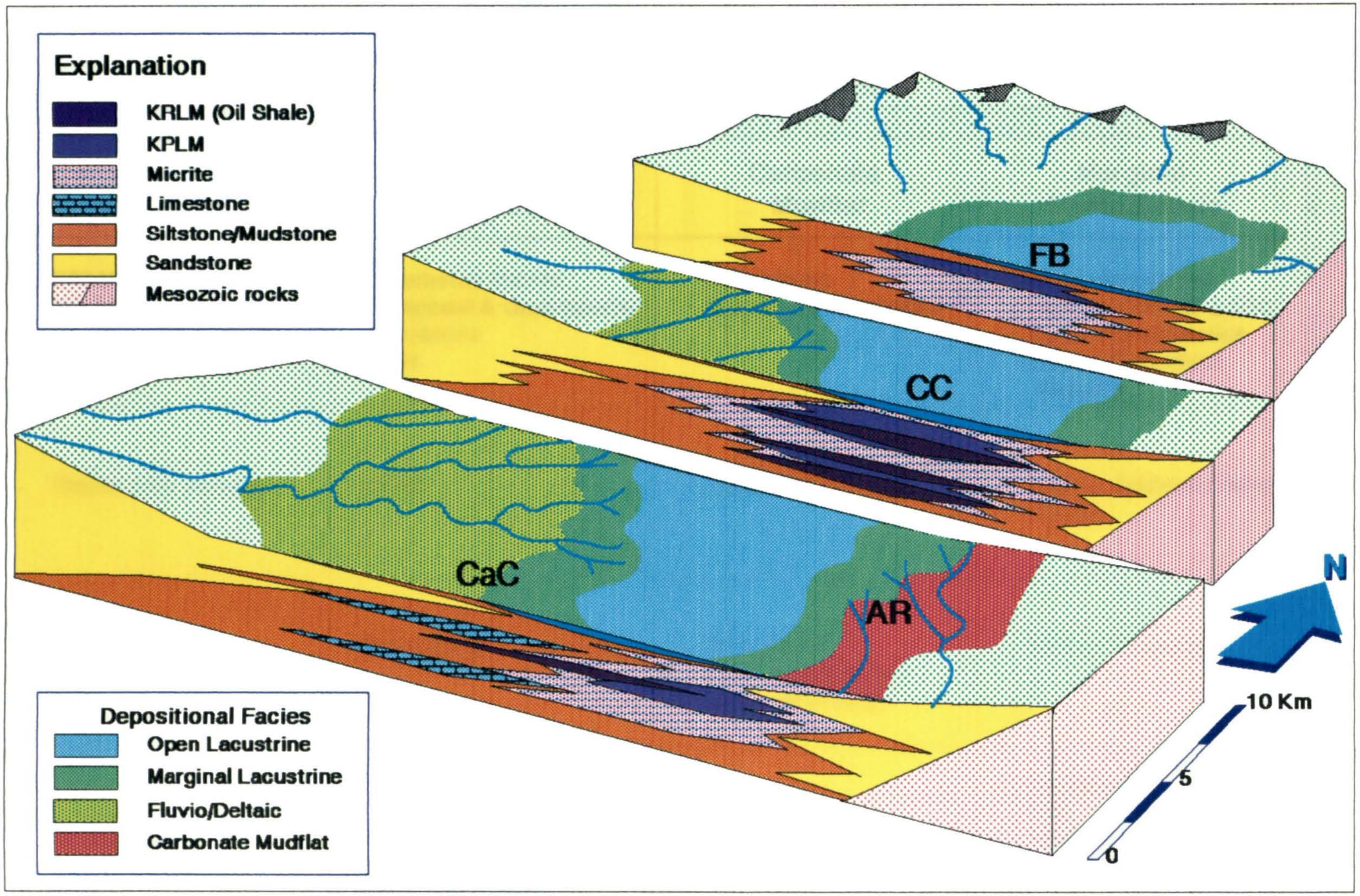


Figure 25. Block diagram illustrating the depositional model for the Lower Unit, Fossil Butte Member. The model depicts the distribution of interpreted depositional environments: open-lacustrine, marginal lacustrine, fluvio/deltaic and carbonate mudflat facies in Fossil Lake as it existed in the Early Eocene.

formed at the depocenter and grades laterally into KPLM. This gradation involves the dilution of kerogen by calcite from depocenter to margin, thickening and increase in the laminae, and subsequently in the marginal-lacustrine facies, an increase in bioturbation, sediments become bedded or massive, and greatly diluted by siliciclastics. Localized siliciclastic deposition took place in the open-lacustrine facies when as a result of storms or other climatic or tectonic events sheet floods or turbidites brought organic rich (plant and organic debris) which was deposited alternately with calcite and kerogen formed in the lake. This resulted in the deposition of cyclic sequences of alternating organic rich MS and KRLM or KPLM which were described earlier.

Fossils are most abundant and the variety greater in the open lacustrine facies. They include ostracodes, gastropods and pelecypods, conchostracans, algae and fish and their coprolites. Plant fragments and other vertebrate remains can also be found in this facies. Insects found in these sediments were probably carried by wind into the central part of the lake. The most common fish found in the open-lacustrine facies is the herring *Knightia* (Figure 20A), with minor occurrences of *Phareodus* and *Priscacara*. Buchheim and Surdam (1981) report this association from the Laney Member of the Green River Formation in the Green River Basin. The gastropods present (Figure 20C-F) are all indicators of fresh shallow water with very low salinities (Hanley 1974, 1976). This is also suggested by the occurrence of conchostracans at least in one KRLM at Chicken Creek. These are common inhabitants of shallow and ephemeral pools and do not tolerate salinities greater than 5‰ (DeDecker, 1988). It is also possible that these organisms where living in very shallow isolated ponds in the marginal areas and were washed into the open-lacustrine environment. Kennedy (1987) studied a sequence of KPLM sediments in the Laney Member of the Green River Formation and found an association of abundant conchostracans, ostracodes and gastropods which were interpreted as living in a shallow well oxygenated lacustrine environment where rapid deposition of KPLM and associated claystone resulted in the excellent preservation of fossils. In addition, as Buchheim and Eugster (1989 in prep.) suggest, the sediments below the water sediment interface could have been anoxic precluding the action of bioturbators, and preserving laminations and fossils intact.

Algae was probably responsible for the origin of kerogen which forms the organic lamination of the calcimicrites as well as for the precipitation (thru their photosynthetic processes) of low-Mg calcite both of which alternate to form the laminated KRLM and KPLM (Dean and Fouch, 1983).

Rocks of the **marginal-lacustrine facies** consist of thinly bedded to massive micrites which closer to the margin become greatly bioturbated, ostracodal and gastropodal limestones (grain-supported), and oolites. These are also dominated by calcite and also exhibit the lateral trends described earlier: KPLM of the open-lacustrine (which also occurs in more marginal settings away from excessive siliciclastic input), grades into bedded to massive micrite (with increased bioturbation) towards the margins. In addition carbonates become greatly diluted by siliciclastics and eventually are replaced by mudstones and siltstones of the fluvio-deltaic facies. Also micrites with gastropods and ostracodes are replaced at the margins by ostracodal and gastropodal limestones (grainstones). In this facies, although not abundant, some beds of oolitic limestone occur.

Fossils found in this facies include fossil fish bones and coprolites, a great abundance of ostracodes and gastropods as well as few bivalves. In some localized marginal areas particular "bone beds" apparently of terrestrial vertebrates (possibly birds)(Figure 20B) suggest the formation of beach 'lag' deposits. This environment is similar to the 'littoral paleoenvironment' of Buchheim and Surdam (1981), since in many marginal carbonates juvenile *Knightia* as well as juvenile gastropods (Figure 20C-F) are found in addition to stems of *Equisetum* (horsetail)(Figure 21E) and *Typha* (cattail), all typical of a littoral environment.

The **carbonate mud-flat facies** is a localized marginal environment. It occurs along the eastern margin of the lake and is well developed at Angelo Ranch. Dolomicrites and ostracodal dolostones are typical of this facies. Dolomite was probably formed on a carbonate mud-flat adjacent to Fossil Lake and resulted from the process of evaporative pumping which concentrated brines with high Mg^{+2}/Ca^{+2} ratios to allow precipitation of dolomite or dolomitization of carbonate muds. This mudflat environment underwent periods of subaerial exposure which in addition to dolomitization produced mudcracks and other dissication features. After transgressive stages of the lake, and increased energy conditions(scour structures) laminated dolomicrite and dolomitic mudcracked sediments were ripped-up and redeposited as dolomitic clasts in other calcitic carbonates. This facies represents very alkaline and saline conditions and typifies a harsh arid environment which did not sustain too much life. Fish as well as the majority of other organisms probably moved to fresher water conditions, and only the very resistant (tolerant) species of ostracodes might have lived in these conditions, as suggested by the presence of ostracodal dolostones. The repeated cycles of dolomitic carbonates, calcitic carbonates and siliciclastics in the Angelo Ranch section, indicate the rapidly changing nature of the environments in Fossil Lake. In an otherwise fresh-water (low salinity) Fossil Lake, this locality (AR) was subjected to several periods of hyper-salinity and very high alkalinity levels. Rapid regression-transgression events coupled with intense evaporation, and fluvial activity in periods of lacustrine transgression, are an indication of the dynamic nature of Fossil Lake's existence.

Fluvio-Deltaic Facies. Fluvial deposits consist of channel sandstone units, thin sandstone and siltstone beds and mudstones, and were deposited in Fossil Lake by streams coming in from the southern regions and probably consistently during the existence of the lake (Figure 5E-F). Sandstones contain various types of ripple marks, as well as trough cross bedding and fining upward sequences, all common features of fluvial and flood plain environments.

The deltaic environment was developed when a modified Gilbert-type and Catatumbo River-type delta prograded into Fossil Lake from the southwest to the northeast. This occurred as the culminating phase of the Lower Unit and constitute the Sandstone Tongue of the Wasatch Formation, which separates the Lower from the Middle Unit of the Fossil Butte Member of the Green River Formation in Fossil Basin. This deltaic unit was documented and studied in detail by Peterson (1987). In that study he determined that the Gilbert-Catatumbo River-type delta developed as a four lobed bird's foot type delta, and prograded into the lake in two separate events: the Alpha and Gamma Phases. Characteristic of this environment are sequences which contain bottomset, foreset, and topset beds, and coarsening upward features. In addition he identified typical deltaic subenvironments: floodplain, distributary channel, delta plain (with interdistributary bay and carbonate mudflat), delta front (including channel mouth bar and sheet sands) and prodelta. A few limestone beds are found interbedded with these deltaic deposits and contain gastropods and pelecypods, and reflect sudden transgressions of Fossil Lake and or paucity in sediment input by the delta. A few reptile fossils have been found in the deltaic sandstones and the siltstones and mudstones contain fish bones, scales, ostracodes and burrows. Some mudstones contain abundant plant fragments. Prodelta mudstones extended as far north as Fossil Butte where it alternates with carbonate laminae in a four meter sequence at the top of the Lower Unit, and as far as Loc 17 (Figure 5B) where it is represented by a thin bed of claystone.

FOSSIL LAKE HISTORY, 'THE BEGINNINGS'

As the tectonic events that formed Fossil Basin took place, the Wasatch Formation sediments immediately underlying the Fossil Butte Member's Lower Unit sediments suggest both an abrupt basin development and fluviatile infilling. The lake thus formed had its center of deposition (from deposition of oil shale in Lower Unit) in the vicinity of the Clear Creek locality (Frontispiece, Figure 16A), around which an open lacustrine depositional facies developed. Here, KRLM (oil shale) and KPLM were deposited from the depocenter towards the margin respectively, alternating with calcareous mudstones. In this environment flourished a rich community, characterized by high productivity, as seen from the abundance of kerogen and fossils preserved in the sediments. Surrounding this open-lacustrine environment was a marginal lacustrine setting which sustained a variety of organisms and facilitated the deposition of micrites, fossiliferous limestones and fluvial originated siliciclastics. These conditions fluctuated dynamically during most of the life of Fossil Lake, when climatic and or tectonic events (including a few volcanic events which deposited ash layers over the bottom of the lake) caused regressions and transgressions, as well as sudden increased input of siliciclastics in the lake by sheet floods or storm processes. After gradual sediment infilling (lacustrine) and a major Deltaic incursion at the end of Lower Unit time, probably due to subsequent subsidence and tectonism (with the deltaic event), the basin depocenter shifted north several miles near Fossil Butte (Figure 5A) where the Middle Unit KRLM (oil shales) are best developed, and constitute the maximum transgression of Fossil Lake. Many sandstone units throughout the Lower Unit in the southern area suggest continuous fluvio-deltaic events in the history of Fossil Lake, with a major deltaic transgression into Fossil Lake from the S-SW which constitutes the end of the Lower Unit sequence and set the stage for the development and deposition of the Middle Unit sediments and fossils.

Conclusions

1. The Lower Unit of the Fossil Butte Member is a well developed lacustrine sequence in the southern half of Fossil Basin. It was deposited mostly in the southern half of Fossil Basin, but extends from the vicinity of Loc 17 to near Hill Creek where it grades into the intertonguing Wasatch Formation. The eastern shoreline of Fossil Lake ran north to south just east of Angelo Ranch. Further studies are needed to determine the western extent of Fossil Lake, but there is good evidence that it might have extended much further west (even during Lower Unit time), possibly up to the vicinity of Bear Lake (Utah).

2. Lithofacies include laminated and non-laminated micrites: KRLM (kerogen rich laminated micrite), KPLM (kerogen poor laminated micrite), bedded to massive micrite (with varying degrees of bioturbation), ostracodal and gastropodal limestone, dolomicrite, and KPLMSil (kerogen poor laminated micrite with high content of clays); siliciclastics: fluvial and deltaic sandstone, siltstone and mudstone; occasional tuff and chert. The absence of saline minerals attest to the fresh (low salinity) nature of the water and the carbonates present indicate the alkaline nature of Fossil Lake.

3. Lithofacies change laterally and vertically; variety and cyclicity indicate a very dynamic system (rapidly changing). These lithofacies were deposited in four major depositional environments: (1) open-lacustrine, (2) marginal-lacustrine, (3) carbonate mudflat, and (4) fluvio-deltaic. The open-lacustrine facies is characterized by KRLM, KPLM and associated calcareous mudstone, well laminated carbonates (organic rich to poor) and preserved abundant fossils, probably by rapid sedimentation and by attaining anoxic conditions below the sediment-water interface. Lamination indicates a low energy environment while the varied fossil fauna suggest shallow fresh water conditions. Lithofacies grade into each other from depocenter to margin, in relationships which are

dependent on calcareous and siliciclastic sediment inflow from the margins, in addition to the combination of a number of factors such as distance from depocenter to margins, changes in depth, oxygenation and water chemistry. At the depocenter of the lake KRLM grades towards the margin into KPLM and subsequently into bedded to massive Micrite, and or fossiliferous limestone (grainstone). Laminae thickness and number increase towards the margins, as organic matter (kerogen) is diluted by calcite deposition first and siliciclastics in the marginal areas. The marginal areas constitute the marginal-lacustrine facies, where micrites are dominant as well as ostracodal and gastropodal limestones. This facies also sustained a varied fauna but preservation is not as good probably due to the action of bioturbators. Another type of marginal facies is the carbonate mudflat, restricted to the Angelo Ranch area where significant subaerial exposure and evaporation was conducive to the formation of dolomite. The fourth depositional facies is the fluvio-deltaic paleoenvironment, characterized by deposition of sandstones, siltstones and mudstones, with some associated limestones. This deltaic environment culminated the lifespan of Fossil Lake during Lower Unit time, and set the stage for a great lacustrine transgression which resulted in the deposition of the Middle Unit sediments.

4. Carbonate deposition was the result of an interaction of physical, chemical and biological factors resulting in a dynamic lake in which continuous slight and sudden fluctuations (regressions/transgressions) resulted in lateral and vertical lithofacies changes reflecting the particular depositional environments.

5. Further study of the minute relationships and variation in lithofacies succession and cyclicity, will give us a better understanding of the chemical and physical mechanisms at play through the time this fascinating formation was deposited.

APPENDIX 1

MEASURED SECTIONS AND LITHOLOGIC DESCRIPTIONS

Locality 17: Watercress Canyon (WC)

Unit Number	Thickness (m)	Description
1	4.1	Silty sandstone, green, grades into WC-2
2	.3	Silty limestone, grades from WC-1, greenish
3	.85	Bioturbated limestone, white
4	.03	Kerogen poor laminated micrite, ochre
5a	.06	Bioturbated limestone, silty, greenish
5b	.55	Bioturbated limestone, buff
6	.08	Kerogen poor laminated micrite, ochre
7	.4	Bioturbated limestone, silty, greenish
8	1.15	Bioturbated limestone, buff
9	.25	Limestone, silty, greenish
10	.07	Tuff, pink, hints of lamination
11	.25	Kerogen poor laminated micrite, greenish, clay rich?
12	1.0	Bioturbated limestone
13	.45	Kerogen rich laminated micrite, Lower Oil Shale
14	1.05	Kerogen poor laminated micrite, well indurated, clinky
15	.03	Tuff: Lower Sandwich Horizon (LSWH)
16	.13	Kerogen poor laminated micrite: LSWH
17	.02	Tuff: LSWH

Locality 207

Unit Number	Thickness (m)	Description
0		Wasatch?, covered slump slope, probably Wasatch
1	1.05	Bioturbated micrite, buff
2	.15	Bioturbated micrite, gray distinct bed
3	1.5	Bioturbated micrite, buff
4	.1	Breccia, orange-brown, with fragments
5	.04	Tuff, pink, K-spar?
6	.55	Kerogen poor laminated micrite
7	.25	Limestone, brown, hard
8	.03	Coal unit
9	.2	Kerogen rich laminated micrite: oil shale
10	1.0	Kerogen poor laminated micrite: "Lower Oil Shale"; grades from unit 9, contains (5) 1/4" tuffs
11	.02	Tuff: Lower Sandwich Horizon (LSWH)
12	.15	Kerogen poor laminated micrite: LSWH
13	.02	Tuff: LSWH

Locality 252

Unit Number	Thickness (m)	Description
1	1.35	Bioturbated limestone, outcrop in lower slope exposed by slump
2	2.7	Limestone, silty, muddy, gray, more silty to top
3	5.5	Bioturbated limestone, slope covered except in this area, steep
4	.6	Bioturbated limestone, outcrop
5	.1	Limestone, brown
6	3.6	Bioturbated limestone, thin-bedded at bottom
7	2.0	Covered
8	.2	Kerogen rich laminated micrite: oil shale, exposed in covered slope
9	1.5	Covered area to Sandwich Horizon zone: exposed ca. 100m West

Locality 217: Fossil Butte (FB)

Unit Number	Thickness (m)	Description
1	2.3	Sandstone, blue-gray, fine-grained, analcimic; crossed with gypsum veins, spheroidal weathering; non-calcareous; pyrite common
2A	.48	Sandstone, abundant dolomite and tuff (analcimic) intraclasts; calcareous; burrowed; top of unit is an oolite with sparry calcite cement and 20% quartz sand grains
3A	.25	Partly burrowed laminated micrite, burrowed, weathered surface appears like a massive micrite
3A	.6	Bioturbated micrite, bluish; well defined burrows; numerous sand size quartz spheres; fish jaw (?); top of unit is an irregular burrowed surface
4A	1.8	Ostracodal dolomicrite; hard, ledge former, mottled; contains many calcite casts that appear to be ooids or ostracodes; sparry calcite cement
4B	.2	Bedded calcimicrite, grades top and bottom; numerous ostracode molds, some filled with sparry calcite; fish bone fragments common
5A	.3	Siltstone, blue-gray, calcareous, bioturbated, appears similar to FB-1; spheroidal weathering; gypsum veins
5B	.2	Tuff, analcimic, sugary texture, quartz rich, contains blue-brown weathering streaks veined with gypsum, iron stained
6	1.1	Bioturbated micrite; burrows well defined; dolomicrite intraclasts; numerous fish bone fragments
7	1.8	Siltstone, blue-gray; spheroidal weathering; crossed hatched with gypsum veins; calcareous (34% calcite), analcimic, pyrite grains common
8	.09	Laminated micrite with thin tuffs and siltstones; alternating quartz and micrite laminae
9	1.7	Laminated dolomicrite, ostracodal, some beds burrowed; ostracodes delineate some laminae; some quartz-rich laminae; some beds with breccia intraclasts; one thin cm thick oil shale
10A	.4	Laminated calcimicrite, partly bioturbated to pseudo-brecciated, ostracodal, some laminae delineated by ostracodes
10B	.84	Bioturbated micrite
12-13	1.26	Bioturbated micrite; partly burrowed in upper 20cm; some dolomicrite beds included
14A	.3	Partly-burrowed laminated micrite
14B	.26	Bioturbated micrite

15A	.5	Partly-burrowed laminated micrite; lenticular laminae
15B	.5	Bioturbated micrite
15C	.25	Pseudobreccia; gastropod observed
15-16	2.5	Bioturbated micrite; contains laminated micrite intraclasts with some disorientation of laminated clasts; large fish bones and fish bone fragments; burrows obvious
17	1.13	Bioturbated micrite with some beds of patchy laminated micrite
18A	.6	Bioturbated micrite with small fish bone fragments
20	.6	Bioturbated micrite; 2cm tuff at base
21	1.05	Bioturbated micrite; contains numerous microtubules; (FB-22: .05m tuffaceous mudstone, fragmented, crudely lam. varies 2-5cm in thickness)
23A	.3	Laminated micrite, greatly disrupted into a disruption Breccia; very abundant fish bones and fish bone fragments (bones acting as sedimentary particles or intraclasts) that grades upward into bioturbated micrite with few fish bone fragments; gar fish in 23C; contains (4) 4mm tuff beds
24-28	1.5	Laminated micrite with burrows interbedded with bioturbated micrite and pseudobreccias; well defined burrows with meniscus fillings; fish bones disrupted by burrows; continues as a laminated micrite (25A) with burrows; grades up into laminated quartz-micrite with alternating quartz and calcite laminae (25B) and finally into a tuffaceous mudstone (25C); 26-28 continue similar lithologies
29-31	.67	Bioturbated micrite
32	.43	Laminated micrite with thin tuff beds
33	.24	Mudstone, brown
34	.12	Bioturbated micrite, disrupted and disarticulated fish bones; burrows extend into lower unit; smells strongly of petroleum
35	.05	Tuff
36	.54	Laminated micrite; contains well defined burrows; fossil fish
36-60	2.2	Alternating mudstones and laminated micrites; mudstones thicker (generally >10cm) than micrites (generally <10cm); micrites contain fish bones and coprolites; some mudstones show streaky lamination; micrites commonly interlaminated with clay laminae; laminae are unusually thick (>5mm) compared to most micrites (<.05mm); some "mudstone" are tuff beds; burrows not uncommon; ubiquitous soft-sediment deformation structures present
61	.79	Mudstone, gray brown to ochre; full of crossed-hatched gypsum veins
62-64	.24	Dolomicrite, highly disrupted and brecciated; looks to have been compacted by overlying beds
65	.12	Tuff; 71% feldspar; contains 29% aragonite; varies in thickness; compacted and laterally pinches and swells; pinched completely out in places; forms ball and pillow load structures, may form intraclasts in 64
66-73	.9	Laminated micrite: Kerogen rich (oil shale, .69m) to Kerogen poor; abundant deformation structures, fossil fish abundant; includes some thin 1cm tuffs (analcime); gar fish in 73
74-75	.12	Dolomicrite, distorted, loaded, squeezed into upper unit
76-77	1.35	Lower Oil Shale: marker bed: kerogen rich laminated micrite; contains fossil fish including gars and coprolites
78	.024	Tuff: Lower Sandwich Horizon: LSWH
79	.13	Kerogen rich laminated micrite; contains copros
80	.01	Tuff: feldspar: LSWH

Locality: Angelo Ranch (AR)

Unit Number	Thickness (m)	Description
1A-1	.3	Calcimicrite: with peloids, dolomite intraclast; faint lamination; graded
1A-2		Calcimicrite: peloids, intraclasts graded out
1A-3		Lenticular Sandstone: current lamination with scour and fill
1B	1.5	Laminated dolomicrite: with graded oolite at top on unconformable surface
2	.3	Dolomicrite: peloids, lenticular: interbedded with mudstone
3	1.2	Laminated micrite: alternated with thin beds/thick laminated zones; burrows; coprolites
4	3.4	Blocky limestone
4A-1		Lenticular micrite: peloids: "step" faulted
4A-2		Lenticular micrite: peloids; fish bones; coprolites
4B		Ostracodal dolomicrite: with bioturbated intraclasts
4C		Bedded micrite: bioturbated
5	2.4	Mudstone: gray-green, bioturbated, mudstone casts of gastropods
6	.7	Interbedded bedded chalky limestone with ostracodal limestone: bioturbated, mudcracks
6B		Lenticular ostracodal dolomicrite: peloids, faint thick lamination, bioturbated, mudcracks
7	1.3	Mudstone: bioturbated
7-1		Lenticular micrite: peloids, bioturbated, burrows
8	1.5	Bioturbated limestone: burrows, disarticulated fish bones
9	1.6	Bioturbated limestone: burrows
10	.65	Bioturbated dolomicrite: bottom pseudobreccia
11	1.4	Bioturbated limestone
12A	.8	Pebble calcimicrite
12B2	.2	Laminated micrite: burrows, contains *Knightia*
13A	2.7	Laminated micrite: burrow, jupiter style laminae
14	1.4	Bioturbated limestone: contains fish, gradational with mudstone
15	2.2	Mudstone with fine interbedded sandstone beds
15A	1.1	Laminated micrite: bioturbated, jupiter style laminae
15B		Sandstone: calcitic, quartz, biotite, feldspar
16A	.3	Sandstone: very fine grained, calcitic, quartz, biotite
16B	.4	Laminated micrite: coprolites, burrows, bioturbated
16C	1.25	Laminated micrite: bioturbated, few thick laminae, quartz (38%)
17-1	.05	Calcimicrite: analcime 49%, quartz 15%
17-2		Sandstone: analcime 16%, very fine grained, compaction cracks with calcimicrite
18A	1.1	Mudstone: chippy, organic fragments, fish bones, shell, nodules (siderite)
18B		Mudstone/calcimicrite: quartz 38%
19	.4	Sandstone: calcitic, fine grained, cross-bedded, calcite 25%, current lineation: N
20	.85	Laminated micrite:
21	.3	Bioturbated limestone: burrows, angular clasts, laminated intraclasts, quartz 32%
22	.3	Sandstone: calcitic, fine grained, biotite
23	1.4	Mudstone-laminite: fossil fish, *Knightia*, scales
24	.7	Sandstone: analcime, gray, rusty veins, analcime 19%, bone fragments
25	1.1	Calcareous sandstone/siltstone, with quartz-calcimicrite with peloids:ripple cross-laminated
26	.5	Laminated micrite: fish fragments, coprolites
27	3.8	Laminated mudstone: tan
28	5.0	Sandstone

29	1.2	Mudstone: quartz 58%
30	3.15	Sandstone: calcareous, biotite
31	1.0	Sandstone: calcareous, biotite
32	.1	Laminated micrite: fine lamination
33		Tuff: Lower Sandwich Horizon

Locality: Fossil Ridge (FR)

Unit Number	Thickness (m)	Description
0	-	Wasatch: red clays, covered, slumped
1	?	Covered slope: tan-buff, jumbled mudstone
2	38.5	Mudstone: clays, light buff slopes, partly covered; top green-gray claystone
3	.3	Micrite: tan-light brown
4	.08	Limestone: redish-brown, thin bedded
5	.9	Micrite: alternated indurated bands, chippy marl in slope
6	.3	Limestone: buff, massive
7	.2	Micrite
8	.9	Limestone: massive
9	.2	Limestone: buff, with small (3-10mm) pebbles embedded
10	.6	Mudstone: silty, tan-brown, grades into laminated Mudstone
11	.35	Kerogen rich laminated micrite: oil shale; paper shale (kerogen poor): fish scales, plant fragments, ostracodes, insect larvae
12	.05	Tuff: bottom with soft sediment deformation
13	.65	Limestone: ostracodes, brown-gray, bluish(weathered), bottom 2cm oil shale, fish
14	.11	Dolomicrite: gy-redish, color banded
15	.01	Laminated micrite: insects
16	.005	Tuff: iron stained
17	.02	Kerogen rich laminated micrite: oil shale: laminae deformation
18	.85	Kerogen poor laminated micrite/Kerogen rich laminated micrite: .4m
19	.3	Laminated micrite with thin (5, 1-3cm thick) mudstone beds: abundant plant fragments
20	1.4	Kerogen rich laminated micrite(1m) with alternating thin mudstone beds (1cm) & tuffs
21	.08	Limestone: massive, hard resistant layer
22	2.0	Kerogen poor laminated micrite: buff, chippy
23	1.5	Micrite: light brown-buff, chippy, top 20cm hard marl grades to Mudstone
24	.8	Mudstone: orange-brown, chippy, top becomes massive, grades to micrite
25	.45	Micrite: light brown-buff, massive resistant layer, grades to laminated micrite
26	1.93	Kerogen poor laminated micrite: gray-brown, with massive layers, coprolites, fish bones
27	5.94	Micrite: alternating massive resistant beds/chippy slope
28	.35	Kerogen rich/poor laminated micrite: grades to thicker laminated micrite
29	3.35	Kerogen poor laminated micrite (1m): reddish brown, with interbedded mudstone: coprolites, fish
30	.05	Mudstone: laminated, brown, very hard, pebble intraclasts
31	.03	Mudstone
32	.15	Mudstone: orange-brown, with thin interbeds of highly organic matter
33	.28	Dolomicrite: gray-brown, massive, base of cliff
34	.15	Kerogen rich laminated micrite: resistant
35	.28	Micrite: yellow-brown, chippy, top massive grades to dolomicrite
36	.07	Dolomicrite: gray-brown, color banded, grades to paper shale
37	.02	Kerogen poor laminated micrite: iron stained
38	.25	Kerogen poor laminated micrite, interbedded mudstone, micrite at top

39	8.4	Kerogen rich laminated micrite (2m)/Kerogen poor laminated micrite, and interbedded mudstone: laminated, dark brown
40	2.0	Silty mudstone: tan slope
41	1.8	Mudstone: dark brown-gray
42	.07	Siltstone: light gray
43	.2	Sandstone: gray, well cemented, fine to medium grained
44	3.0	Mudstone: laminated in part, dark brown-yellow-brown
45	.6	Lower oil shale: below Lower Sandwich Horizon
46	.03	Tuff: Lower SWH
47	.08	Kerogen rich laminated micrite: LSWH
48	.02	Tuff: LSWH

Locality: Clear Creek (CC)

Unit Number	Thickness (m)	Description
0	12.0	Alluvium/soil: carbonate and mudstone fragments, slope
1	1.1	Dolomicrite: tan, calcite 15-25%, quartz 15-25%
2	.7	Kerogen rich laminated micrite: oil shale: dark-brown, fish scales, 3 cycles
3	.4	Dolomicrite: same as CC-1
4	.04	Tuff: analcime 45%
5	.2	Laminated micrite: dolomicrite: analcimic (30%), Calcite (22%)
6	.1	Claystone: analcime 50%, quartz 35%
7	3.0	Kerogen rich laminated micrite: 3 resistant ledges traced laterally, very black, coprolites
8	1.6	Kerogen poor laminated micrite: marly, fish scales
9	3.1	Micrite: massive, blocky, buff
10	.3	Mudstone: tan
11	1.0	Kerogen rich laminated micrite: prominent ledge, abundant fossils: ostracodes, insects
- - - - - - -	- - - - - - -	Continued 200m W on brown hill
12	1.1	Micrite: marly mudstone, buff slope
13	.8	Laminated micrite(KPLM): marly, slope
14	.2	Silty mudstone: brown, indurated, little bench
15	.3	Micrite: tan gray, chippy
16	.5	Silty mudstone: same as CC-14
17	2.6	Interbedded micrite(1.3m) and silty Mudstone: buff slope, 6 cycles
18	.9	Laminated micrite (KPLM): little ledge, brown slope starts
19	3.8	Interbedded Micrite (2m) and mudstone: brown slope, top 40cm indurated, fish fragments, 5 cycles
20	.3	Laminated micrite (KPLM): edge of bench
21	.2	Siltstone: gray, chippy with clasts
- - - - - - -	- - - - - - -	Continued 100m W under sandstone cliffs
22	1.4	Laminated micrite(KPLM): brown slope with shale ledges: thin mudstone interbeds
23	.015	Limestone
24	1.6	Laminated micrite (KPLM): with some mudstone interbeds; nice brown oil shale bench
25	10.0	Mudstone with several siltstone and laminated micrite (3m) interbeds: tan slope under sandstone cliffs; mudstones analcimic (50%), quartz (40%)
26	15.0	Sandstone: delta sandstone, cliffs, planar and cross-beds, very coarse grained
27	1.5	Siltstone: buff-brown
28	.3	Sandstone lens
29	4.0	Siltstone/mudstone: brown
30		Lower Sandwich Horizon

Locality: Chicken Creek (ChC)

Unit Number	Thickness (m)	Description
1	-	Claystone: green-gray, partly covered; 50% analcime, 25% quartz
2	.12	Micrite, Kerogen poor laminated micrite (KPLM): buff
3	2.31	Claystone: green-gray, same as ChC-1; 55% analcime, 30% quartz
4	.4	Micrite: light brown
5A	.12	Kerogen poor laminated micrite
5B	.38	Micrite: bedded, plant fragments, 1-2cm interbeds of green-gray claystone
6	.4	Claystone: light brown, white weathered surface
7	.2	Mudstone: olive green
8	.2	Mudstone: brown
9	.3	Mudstone: green-gray, grades to ChC-10
10	.25	Limestone: marly, grades top and bottom
11	.8	Mudstone: green-gray-tan, grades at bottom
12	.65	Limestone: white bench
13	.5	Micrite: slope, chippy
14	.06	Limestone: laminated
15	.15	Micrite: faintly laminated
16	1.65	Mudstone: green-gray
17	.2	Mudstone: claystone: shaly, abundant plant fragments (3-5mm)
18	1.8	Micrite: 30% dolomite, 20% analcime
19	.06	Limestone
20	.01	Tuff: orange
21	.54	Limestone: poorly laminated, copros, 2-10cm organic film
22	1.79	Mudstone: green-gray, ostracodes
23	.31	Laminated micrite: coprolites
24	.09	Micrite: grades into lower unit
25	3.36	Lower Brown Layer: interbedded cyclic Mudstone and Laminated micrite, description: Sampled 3 separate intervals: I, II, and III
IA	.11	Micrite: basal, blocky, green-brown-gray, ostracodes; 90% calcite, 5-10% analcime
IB		Contact A-C
IC	.32	Kerogen poor laminated micrite: paper shale, fossil fish (*Knightia*), coprolites, fish scales; 70% calcite, 25% dolomite/ankerite, 5% analcime
ID	.11	Mudstone: gray-brown-redish, 45% quartz, 10% k-spar, 20% Calcite, 10% analcime
IIA		Mudstone: brown-gray, base of cycle; 40% Analcime, 30% quartz, 25% Calcite
IIB		Kerogen poor laminated micrite: fish fragments, plant fragments; 90% Calcite, <5% quartz
IIC		Mudstone: green-gray, base; 50% quartz, 30% calcite, 10% dolomite
IID		Kerogen poor laminated micrite: fish scales, gastropods (1-3mm), ostracodes; 95% calcite, <5% quartz
IIIA	.38	Kerogen poor laminated micrite: 95% calcite, <5% quartz
IIIB	.04	Mudstone: 45% quartz, 20% analcime, 20% calcite, 10% feldspar
IIIC	.05	Kerogen poor laminated micrite: green-brown, 60% calcite, 20% analcime, 10% quartz
IIID	.015	Mudstone: red-brown
IIIE	.4	Kerogen poor laminated micrite: tan, paper shale
IIIF	.12	Mudstone: green-gray-brown, chippy
IIIG	.24	Mudstone: laminated, resistant, with iron stained pellets
IIIH	.15	Mudstone: gray-brown
26	.33	Siltstone: brown-tan, ledge, soft sediment deformation, laminated

27	.03	Mudstone: green
28	.2	Siltstone: brown, small ledge, baby gastropods
29	.45	Mudstone: green
30	.27	Mudstone: brown, resistant ledge
31	.17	Mudstone: green
32	.11	Siltstone: tan, baby gastropods (1-2mm), ostracodes, burrows
33	.09	Mudstone: green
34	.02	Siltstone
35	.06	Mudstone: green
36	.1	Mudstone: well indurated, small ledge, burrows
37	.55	Micrite: brown, 90% calcite, 10% quartz
38	.12	Mudstone: green, 65% quartz, 15% calcite, 5% feldspar
39	.27	Micrite: hard ledge
40	.46	Mudstone
41	.1	Siltstone: grades to mudstone below, fish fragments
42	.1	Mudstone
43	.15	Limestone: white, last white ledge: below is tan-brown layer
44	.98	Mudstone: claystone, buff-brown, below ledge, traced laterally
45	.63	Limestone: forms prominent white ledge
46	.95	Mudstone: olive green, chippy, slope
47	1.68	Laminated micrite at bottom 70cm Limestone: laminated, fossil fish, bench, .2m Micrite at top: 80% calcite, 20% dolomite/ankerite, <5% quartz
48	2.68	Dolomicrite: green-gray, in slope, chippy; 53% dolomite, 35% calcite, 10% quartz
49	.28	Micrite: olive-green; 50% calcite, 30% dolomite, 10% quartz
50	.5	Mudstone: gray-tan, green-gray, very noticeable in slope, ostracodes
51	.56	Mudstone: brown
52	.27	Mudstone: gray
53	.2	Kerogen poor laminated micrite: fossil fish (*Knightia*: 10cm)
54	.06	Mudstone
55	.96	Micrite
56	1.6	Kerogen rich laminated micrite: 1m, grades to kerogen poor laminated micrite (paper shale): with fish scales, coprolites
57	.09	Mudstone: green-gray
58	.21	Kerogen poor laminated micrite
59	.1	Mudstone: green-gray
60	.91	Micrite: massive, fossil fragments, petroliferous odor; bottom .2m is laminated
61	.05	Chert: resistant layer, just below limestone bench
62	.5	Limestone: massive, fish scales, forms bench
63	.6	Micrite: slope
64	.2	Mudstone: green, chippy, slope
65	.32	Micrite: slope
66	1.68	Mudstone: slope
67	.31	Laminated micrite; .15m is oil shale: barely visible outcrop
68	.58	Interbedded micrite/mudstone
69	.5	Micrite: green-gray, 70% calcite, 20% dolomite/ankerite, 10% quartz
70	.05	Tuff: well indurated, smooth top, 45% analcime, 20% K-spar, 20% plagioclase, 5% quartz
71	1.1	Kerogen rich laminated micrite: resistant ledge: abundant fish, insect, larvae, coprolites, ostracodes, conchostracans, petroliferous odor, 75% aragonite, 20% calcite
72-73	3.0	Mudstone: dark brown, laminated
74	.5	Kerogen poor laminated micrite: tan-brown, top is oil shale, ostracodes
75	1.68	Mudstone: gray to tan slope, abundant scales, bone fragments
76	1.13	Mudstone: tan to yellow, in slope
77	1.81	Mudstone: brown slope

78	1.25	Mudstone: green, chippy, slope
79	.03	Limestone: resistant layer, redish, thinly laminated
80	2.63	Sandstone: coarse at bottom to fine grained at top
81	.35	Mudstone: tan, fish scales
82	2.36	Sandstone: fine grained, buff
83	.76	Mudstone: brown, chippy
84	.56	Mudstone: green-gray, chippy, slope, ostracodes
85	2.96	Mudstone: claystone, green-brown-gray, slope
86	.2	Kerogen rich laminated micrite: brown-dark brown, ostracodes, fish, grades to ChC-88
87	.26	Kerogen poor laminated micrite
88	.42	Limestone: faint lamination
89	2.26	Micrite: tan-brown, chippy, 60% calcite, 30% dolomite, 10% quartz
90	.56	Limestone: ostracodes, vertical burrows, edge of bench
91	2.07	Mudstone: cream, slope
92	.58	Limestone: ostracodes, cream bench
93	2.08	Micrite: buff-brown, slope
94	1.7	Mudstone
95	.4	Sandstone
96	1.6	Mudstone: gray
97	1.27	Sandstone
98	.9	Siltstone
99	4.2	Sandstone: delta foresets, parallel laminated calcitic sand
100	.25	Limestone: bioturbated, abundant *Goniobasis*
101	1.5	Mudstone: claystone, green, slope
102	.12	Sandstone: reddish, coarse, possible ripple cross lamination
103	.82	Mudstone: claystone, green
104	.8	Sandstone: yellow, fine grained
105	4.3	Mudstone/Siltstone: green, coarsening up to fine grained sandstone
106	.4	Limestone: bioturbated, *Goniobasis*, *Unio?*, microtubules
107	.2	Mudstone: claystone, green
108	.44	Sandstone: gray, very coarse granules
109	.6	Siltstone: light green, calcitic
110	.22	Micrite: bioturbated, grades from below
111	2.0	Siltstone: green
112	.5	Sandstone: fine grained, light green-yellow, bioturbated
113	.7	Siltstone: green
114	.14	Limestone: bioturbated, abundant *Goniobassis*
115	.8	Mudstone: green
116	.22	Sandstone: gray, medium grained
117	1.0	Siltstone: green
118	.6	Sandstone: green-gray, fine grained
119	.3	Siltstone: light green
120	.12	Limestone: bioturbated, *Goniobasis*, *Unio*
121	.3	Mudstone: claystone, some silt
122	.07	Sandstone: bioturbated
123	.2	Siltstone: light green
124	.32	Limestone: bioturbated, forms chips in slope
125	.3	Mudstone: claystone, shaly, dark green
126	1.0	Sandstone: very fine grained, yellow-green, silty
127	.3	Sandstone: green-yellow, bioturbated
128	1.15	Mudstone: green-brown, silty
129	.7	Sandstone: gray, biotite, magnetite
130	1.7	Micrite: silty, light brown-gold, small siltstone channel
131	.8	Mudstone: green
132	.35	Siltstone channel in mudstone

133	.9	Mudstone
134	.3	Sandstone: gray, coarse grained
135	1.6	Mudstone: claystone, calcitic, organic rich near top, dark brown-gray
136	.8	Kerogen poor laminated micrite: deformation, cracks
137	.06	Lower oil shale: abundant fish, insects, flowers
138	.6	Laminated micrite
139	.1	Laminated micrite: dark brown, ostracodes
140	.02	Tuff: Lower Sandwich Horizon (LSWH)
141	.10	Laminated micrite: LSWH
142	.02	Tuff: LSWH

Locality: Bear Divide (BD)

Unit Number	Thickness (m)	Description
0	-	Mudstone: green/gray/red: clayey, slumped, Wasatch Formation
1	.4	Limestone: gray-brown, massive, knobby
2	3.4	Micrite with interbedded laminated and non-laminated mudstone: grades up to laminated
3	11.0	Laminated micrite: Kerogen poor, soft sediment deformation, gastropods; 20cm gastropod and bony (vertebrates, birds?) limestone
- - - - - - - -	- - - - - - - -	Moved over 200m SW: correlated over with unit BD-10
10	1.0	Mudstone: massive, green-gray, grades into laminated micrite (.5m), petroliferous odor
11	.1	Laminated micrite: petroliferous odor
12	2.3	Mudstone with interbedded laminated micrite(1.5m): fossil fragments
13	.2	Mudstone: laminated
14	.18	Siliceous kerogen poor laminated micrite: fossil fragments
15	5.3	Interbedded laminated micrite/Mudstone: 6 cycles, including 1m of oil shale: contains ostracodes, plant and fish fragments
15A1		Mudstone: green, 50% quartz, calcite, dolomite
15A2		Dolomicrite: tan, 75% dolomite, 15% calcite, 10% quartz
15B		Oil shale: 60% Calcite, 35% quartz
15C		Laminated dolomicrite: 50% dolomite/ankerite, 35% calcite, 10% quartz
16	.4	Mudstone: top of cyclic slope
17	.6	Limestone
18	.5	Mudstone
19	.3	Limestone
20	.2	Mudstone
21	1.0	Micrite
22	1.0	Kerogen poor laminated micrite
23	1.0	Limestone
24	.5	Mudstone: calcitic, grades into bluish mudstone/siltstone
25	.5	Micrite
26	11.2	Kerogen poor laminated micrite: forms slope up to limestone ledge, with mudstone beds
27	.6	Limestone: gray, fish bone fragments
28	.4	Mudstone: gray
29	.6	Limestone: massive, top of longest bench
30	1.5	Mudstone: marly, slope
31	4.0	Kerogen poor laminated micrite
32	12.0	Interbedded micrite(2m)/mudstone/siltstone: slope, greenish near top
33	.5	Kerogen poor laminated micrite

34	.5	Mudstone: silty, green-gray, slope
35	.5	Kerogen poor laminated micrite
36	4.0	Siltstone: chippy, coarse at base, slope
37	.9	Sandstone: fine grained, light gray, ripple cross lamination, thinly bedded
38	2.0	Siltstone: gray, coarse, slope
39	.65	Limestone: tan, weathers white, blocky, very white ledge
40	.5	Micrite: slope
41	.2	Limestone: white bench
42	4.0	Interbedded micrite(2m)/mudstone and siltstone: white slope, grades up to green siltstone
43	1.5	Kerogen poor laminated micrite: in slope, tan
44	.3	Laminated micrite: ledge
45	1.3	Siltstone: dark gray, clayey
46	.2	Limestone: buff, blocky (2nd bench from sandstone cliffs)
47	1.0	Micrite: chippy, slope
48	.4	Kerogen rich laminated micrite (oil shale): papery, fossil fish, insects (Hidebed)
49	1.5	Siltstone
50	1.5	Kerogen rich laminated micrite (oil shale): resistant ledge, abundant fossil fish
51	6.0	Interbedded siltstone and mudstone: gray slope
52	.4	Sandstone
53	1.5	Siltstone
54	4.5	Limestone: buff, thinly bedded, 3 benches interbedded with micrite slopes
55	13.0	Siltstone: dark gray, weathers blue-gray, thinly laminated, clayey
56	.3	Limestone: tan
57	.2	Siltstone: dark gray, clayey
58	7.0	Sandstone: green-gray, fine to coarse grained, cross bedded, major cliffs
59	3.4	Siltstone: dark gray, weathers blue-gray, clayey
60	1.7	Limestone: 3 beds interbedded with mudstone
61	3.6	Siltstone: dark gray, clayey
62	1.3	Sandstone: fine to medium grained, green-gray, planar beds
63	4.6	Siltstone: blue-gray, soil covered
64	2.2	Sandstone: gray-brown, very coarse grained, with granular base to medium grained at top
65	12.0	Mudstone
66		Lower Sandwich Horizon

Locality: Sheep Creek (ShC)

Unit Number	Thickness (m)	Description
1	5.0	Siltstone: green-brown, tan slope
2	1.8	Sandstone: medium grained, tan, weathered
3	2.8	Siltstone: olive green, buff-green slope
4	.3	Kerogen poor laminated micrite: insects, plant fragments, fossil fish
5	3.1	Siltstone: olive green, slope
6	.3	Limestone: laminated, baby gastropods (*Goniobasis*)), fish fragments, scales, coprolites
7	7.1	Siltstone: olive green, light tan slope
8	1.5	Kerogen poor laminated micrite: papery, with .5m of oil shale, plant fragments, fish, ostracodes, gastropods
9	.4	Limestone: blocky, bedded, top .2m laminated, with abundant ostracodes, gastropods
10	.4	Micrite: top .2m laminated

11	.6	Siltstone
12	.3	Kerogen poor laminated micrite
13	.1	Siltstone
14-1	.25	Kerogen poor laminated micrite
14-2	1.4	Siltstone: slope
15	.3	Kerogen poor laminated micrite
16	3.2	Siltstone: buff, green-tan slope
17	.5	Sandstone: fine grained, blue-gray
18	1.4	Siltstone: buff slope
19	.2	Limestone: brick red (weathered), ostracodes, 57% calcite, 34%dolomite/ ankerite, 3% quartz, <2% plagioclase
20	.8	Siltstone
21	.7	Sandstone: medium to coarse grained, gray, ripple cross laminated
22	1.6	Siltstone: light tan slope
23	3.4	Sandstone: gray, medium grained, trough cross bedded (like channel sand)
24	3.4	Siltstone: brown slope near top
25	.1	Limestone
26	5.0	Siltstone: tan slope
27	.5	Sandstone
28-33	30.0	Interbedded sandstone and siltstone, with redish stain
34	-	Lower Sandwich Horizon

Locality: Carter Creek (CaC)

Unit Number	Thickness (m)	Description
0	-	Covered; 100m to beaver ponds
1	5.0	Siltstone: light brown, slope
2	2.0	Sandstone: light gray, medium grained, trough cross bedded
3	3.0	Siltstone: olive green, slope
4	2.5	Sandstone: light gray, medium to coarse grained, medium bedded
5	11.6	Siltstone: with 5 sandstone stringers (20-50cm thick)
6	.7	Kerogen poor laminated micrite: fossil fish fragments, coprolites
7	5.0	Siltstone: buff-olive green, slope
8	4.0	Sandstone: fine grained, medium bedded, ripple laminated (delta sandstone 50m west)
9	5.0	Siltstone: green-brown slope
10	1.0	Laminated micrite/limestone: at bottom oil shale, papery; ostracodes
11	18.7	Siltstone: slope, with 5 sandstone stringers: pelecypods
12	.15	Limestone: tan, weathers pink-orange, bone fragments
13	1.8	Siltstone
14	2.0	Sandstone
15	12.2	Siltstone: slope with 4 sandstone stringers, in middle sandstone 1m thick
16	4.9	Sandstone: redish ledges, 2 30cm siltstone interbeds, light green
17	3.0	Siltstone: mostly maroon-brick red, stains other siltstones and sandstones
18	1.5	Sandstone
19	9.5	Siltstone: with sandstone interbeds: blocky sandstone like channel sands
20	2.5	Sandstone: last sandstone bench at top
21	.5	Siltstone: olive green
22	.5	Limestone: bioturbated, light gray
23	1.5	Siltstone: maroon-brick red slope
24	.5	Sandstone: thickens into channel to E
25	6.8	Siltstone
26	1.0	Micrite: silty, buff top of slope

27	.5	Limestone: tan-gray, ostracodes, baby gastropods (1-2mm)
28	-	Lower Sandwich Horizon

Locality: Sheep Creek/Little Muddy Creek (S/LMC)

Unit Number	Thickness (m)	Description
1	11.5	Siltstone: blue-green, olive green, slope
2	.4	Limestone: olive green, massive, bioturbated, gastropods
3	.5	Siltstone: olive green, slope
4	.2	Limestone: light tan-gray, bioturbated
5	.4	Siltstone: olive green, slope
6	.1	Limestone
7	.3	Siltstone
8	.05	Limestone
9	.5	Siltstone: green slope
10	.75	Micrite: first white bench
11	.9	Siltstone: olive green slope
12	.2	Limestone: olive green
13	.8	Siltstone: olive green slope
14	.5	Micrite: chippy, white bench; fish scales, bone fragments
15	2.3	Siltstone: olive green, buff-green slope
16	.2	Micrite: buff
17	3.6	Siltstone: olive green, chippy, slope
18	.5	Limestone: olive green-brown, bioturbated
19	1.4	Siltstone: olive green
20	.15	Limestone: olive green
21	.4	Siltstone: olive green
22	.85	Micrite: gastropods (*Omalodiscus, Physa*), 2nd white bench
23	.65	Siltstone: olive green
24	.2	Limestone: laminated
25	.4	Siltstone
26	.2	Limestone: well laminated, bioturbated
27	11.0	Siltstone: tan slope, with thin (30cm) limestone interbeds
28	.2	Limestone: gold-tan bench
29	7.0	Siltstone/mudstone: tan buff slope
30	2.4	Kerogen poor laminated micrite: 40cm at bottom is oil shale; mudstone interbeds; fish scales, coprolites, gastropods, reed carbonizations, plant fragments
31	2.3	Siltstone: olive slope; with micrite interbeds (.5m)
32	1.0	Micrite: chippy
33	2.4	Siltstone/mudstone: tan, buff slope
34	.4	Micrite
35	2.6	Siltstone: buff
36	.5	Limestone: buff, gastropods
37	1.1	Siltstone
38	.4	Limestone: top bench
39	8.5	Siltstone: with thin limestone interbeds(.5m), tan brown slope
40	.05	Ostracodal limestone: top of ridge

Locality: Hill Creek (HC)

Unit Number	Thickness (m)	Description
0	4.0	Siltstone: buff slope (100m to road)
1	.1	Limestone
2	2.0	Siltstone: brown bottom, blue-green top, gypsum, slope
3	.1	Limestone
4	2.5	Siltstone: tan-brown bottom, blue-green top
5	.05	Limestone: tan, 1st tan-gold bench, fine laminations
6	4.0	Siltstone: green-blue bottom, tan top
7	.1	Limestone: chippy
8	1.5	Siltstone
9	.05	Limestone: silty, top of 1st white bench
10	8.5	Siltstone: brown slope
11	.1	Limestone
12	23.0	Siltstone/mudstone interbeds: brown, top 2m green
13	.8	Laminated micrite (.6m)/siltstone: ostracodes
14	.5	Limestone
15	2.0	Siltstone: brown slope
16	1.9	Sandstone: delta foresets, fine grained, light gray, 1st blocky sandstone cliff
17	.2	Siltstone
18	.4	Sandstone: blue-gray, fine grained, massive, honeycomb weathering
19	4.9	Siltstone: olive green, chippy, tan slope
20	1.2	Sandstone: green-gray, very fine grained, medium bedded
21	7.0	Siltstone/mudstone interbeds: olive green bottom half, maroon-red 1m in middle, olive green top
22	.4	Limestone: laminated, slabby, fossil fish, coprolites, bioturbated
23	1.4	Siltstone: brown slope
24	1.9	Sandstone: light gray, medium grained, trough cross bedded, soft sediment deformation
25	2.1	Siltstone: brown slope, olive green with red interbeds
26	2.1	Sandstone: light tan-gray, coarse silt base to fine grained sandstone at top, carbonate clasts, honeycomb weathering
27	1.7	Siltstone
28	1.0	Limestone: laminated, *Goniobasis*, gastropods, fish fragments, ostracodes
29	.3	Siltstone: olive green
30	.2	Limestone: ostracodes, bioturbated
31	1.0	Siltstone: olive green-gray
32	.5	Limestone: orange-tan, ostracodes
33	1.5	Siltstone: olive green-dark gray
34	.4	Limestone: dark brown, chippy, darker to top
35	25.0	Covered slopes: light tan, then red slope, then ca.8m sandstone cliff
		Top of ridge gold-buff of Middle Unit

APPENDIX 2

STRATIGRAPHIC SECTIONS

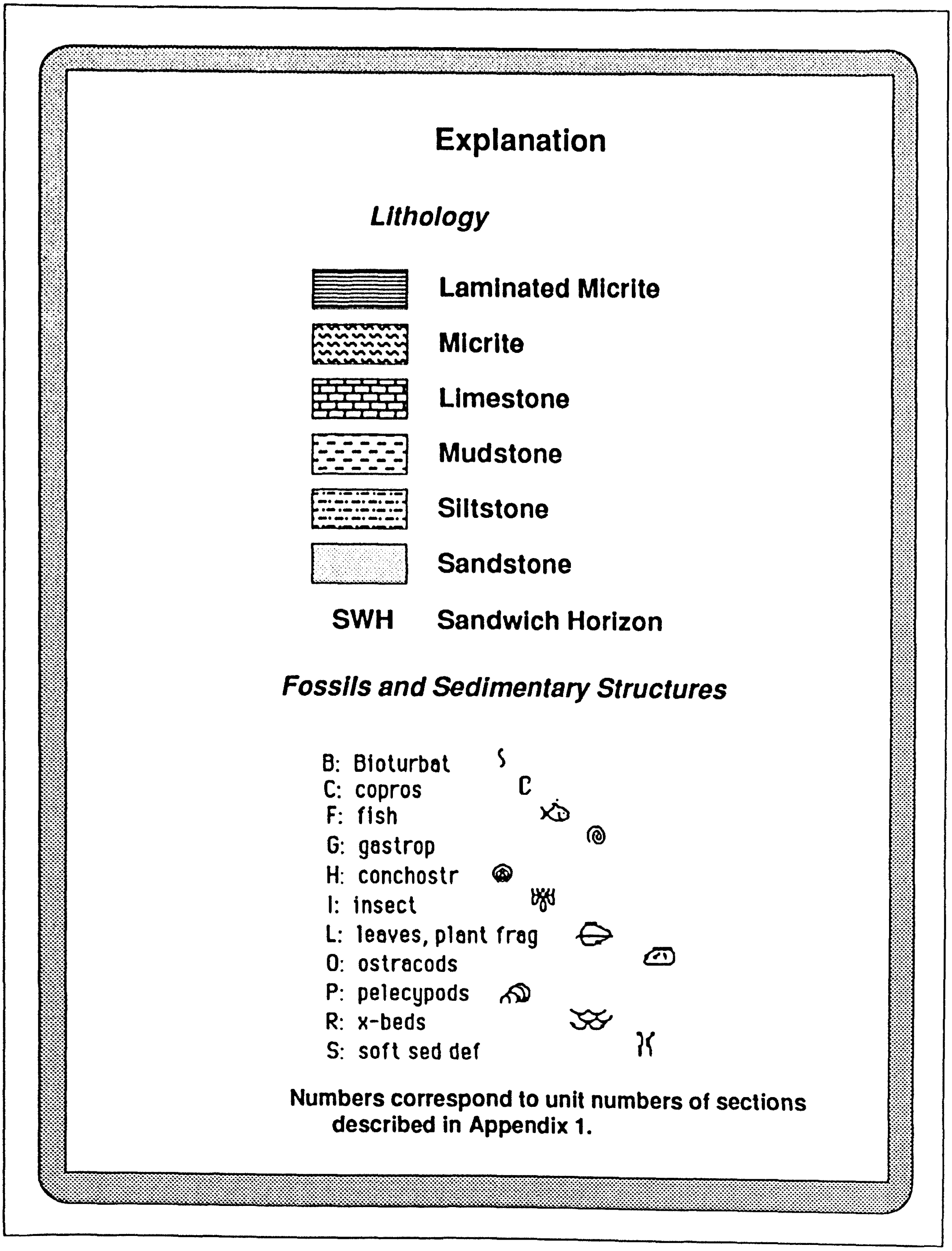


Figure 26. Symbols used in stratigraphic section of figures 27-36.

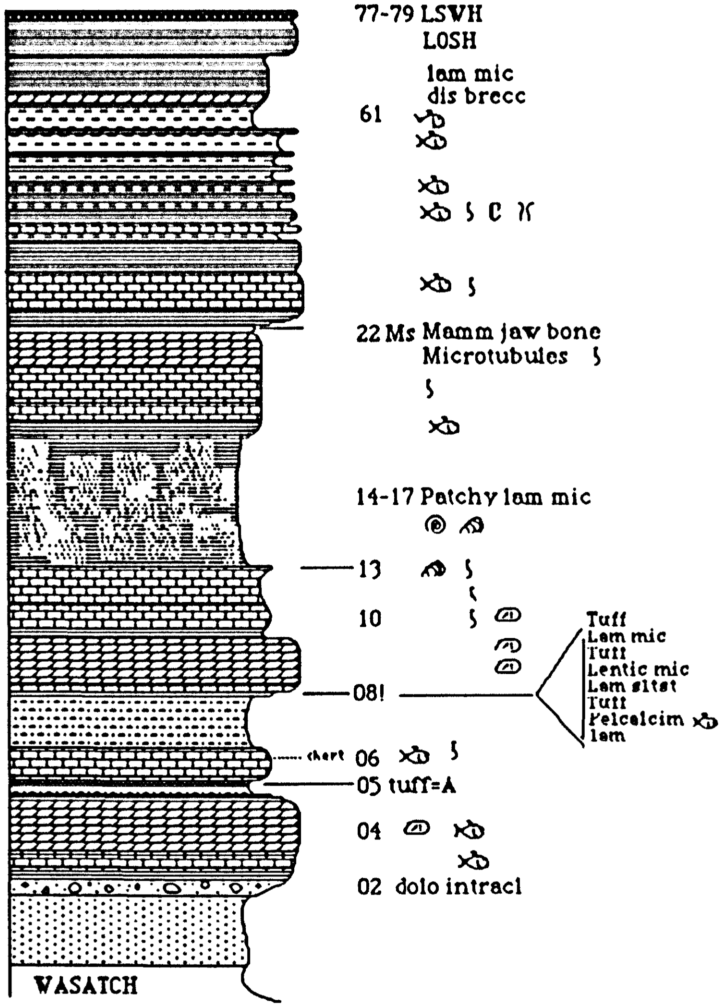


Figure 27. Fossil Butte (FB) stratigraphic section.

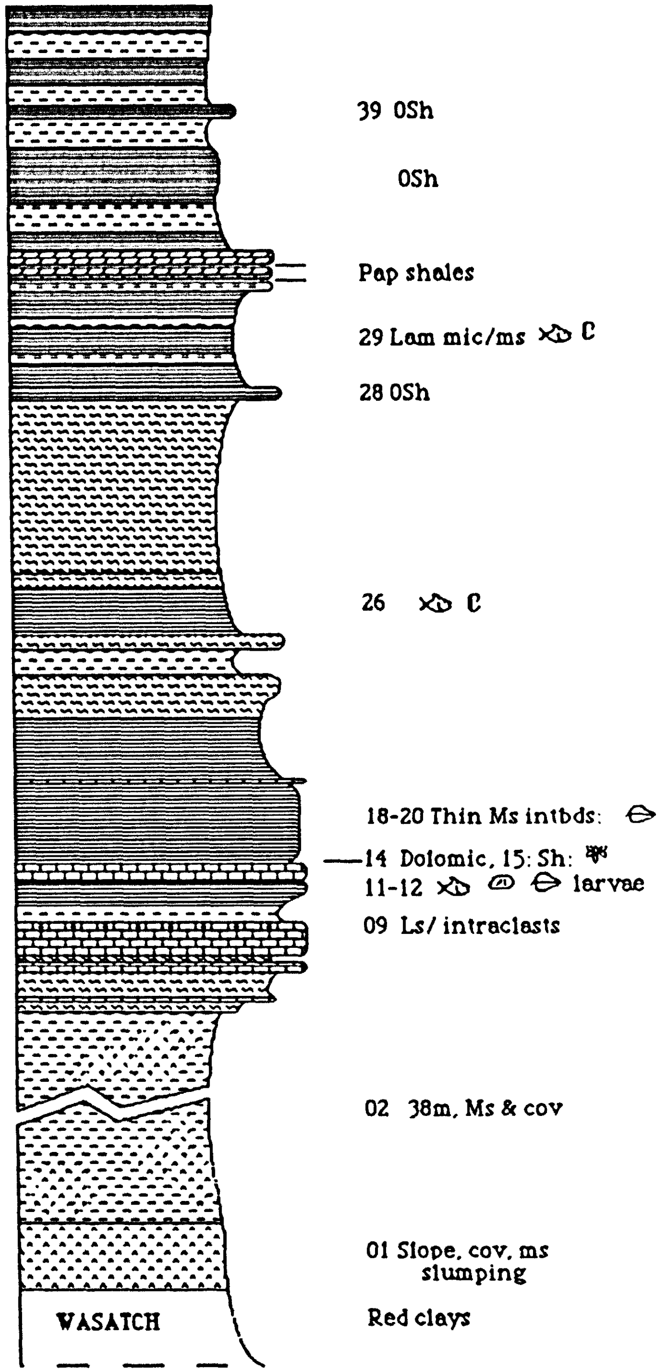


Figure 28. Fossil Ridge (FR) stratigraphic section.

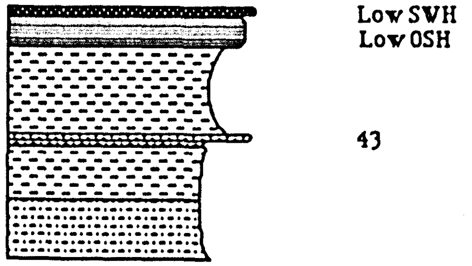


Figure 28 (Cont.). Fossil Ridge (FR) stratigraphic section.

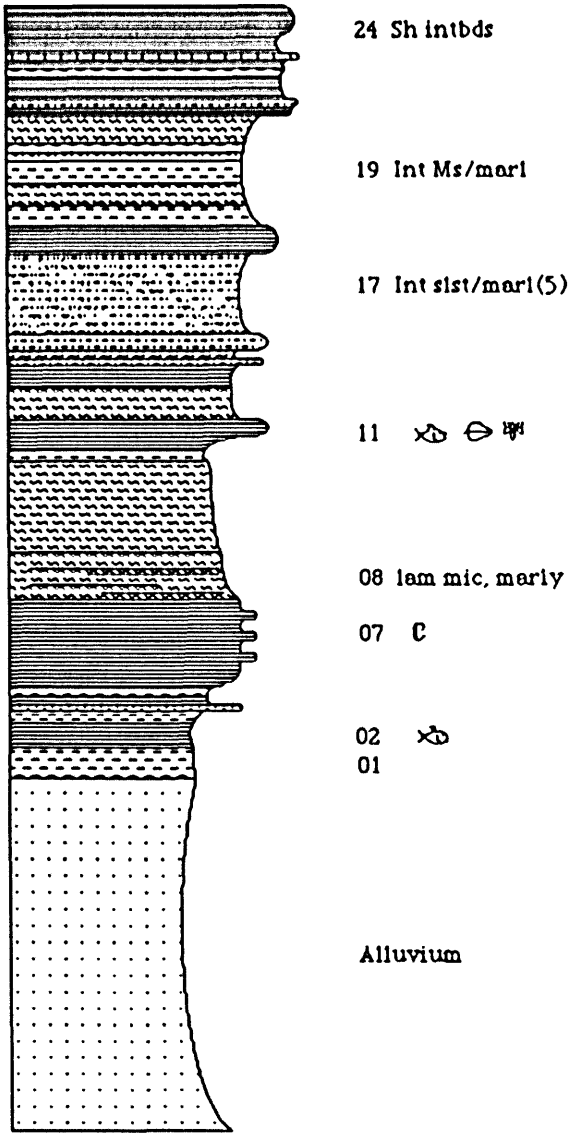


Figure 29. Clear Creek (CC) stratigraphic section.

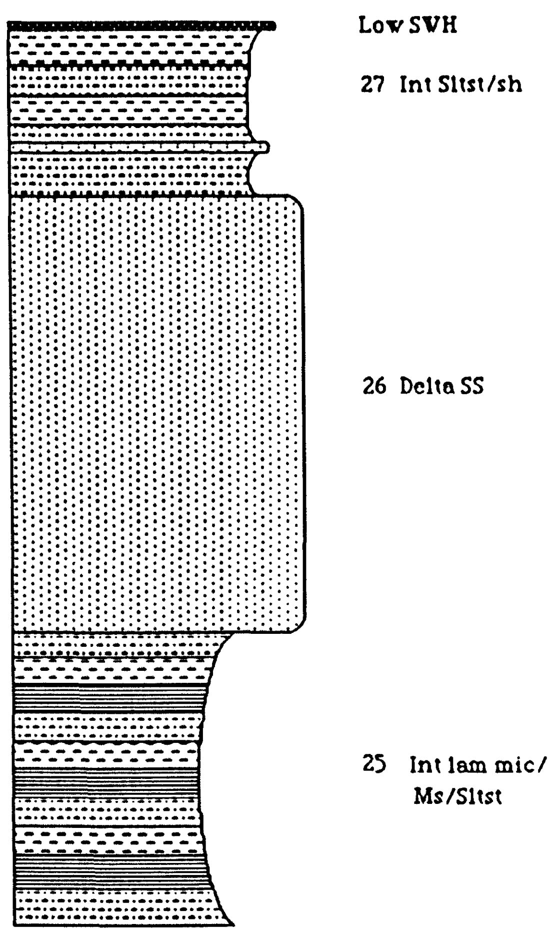


Figure 29 (Cont.). Clear Creek (CC) stratigraphic section.

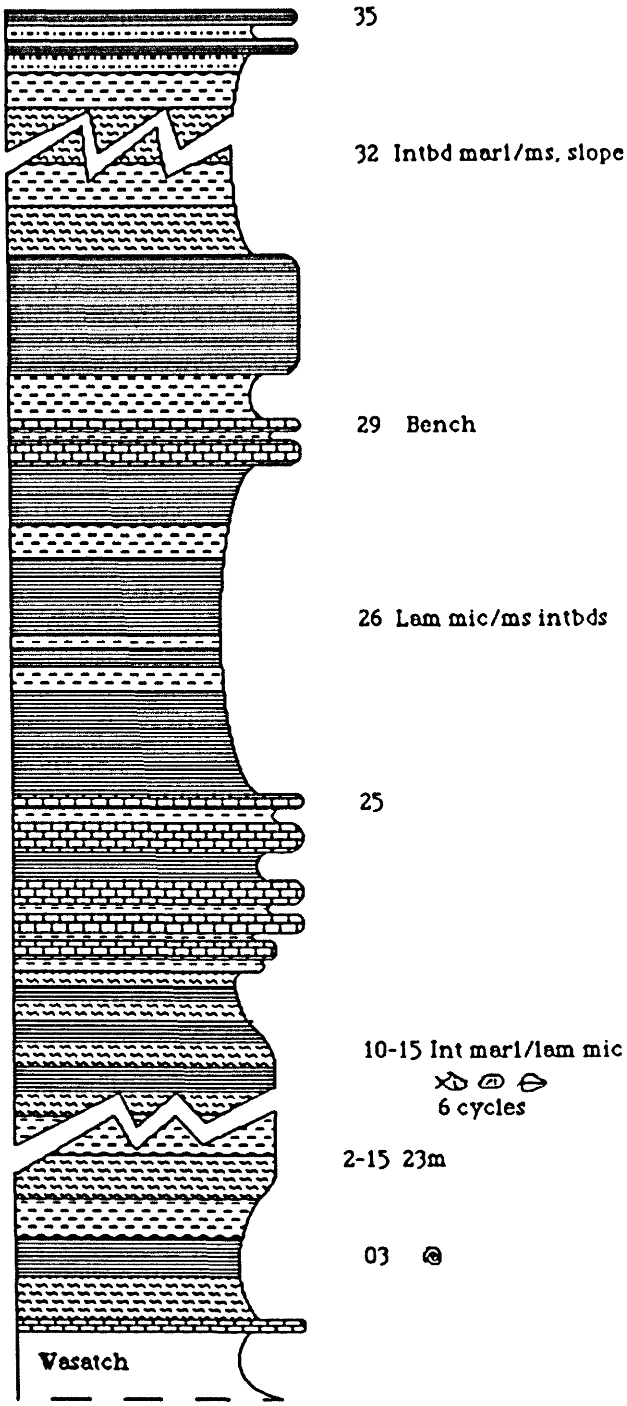


Figure 30. Bear Divide (BD) stratigraphic section.

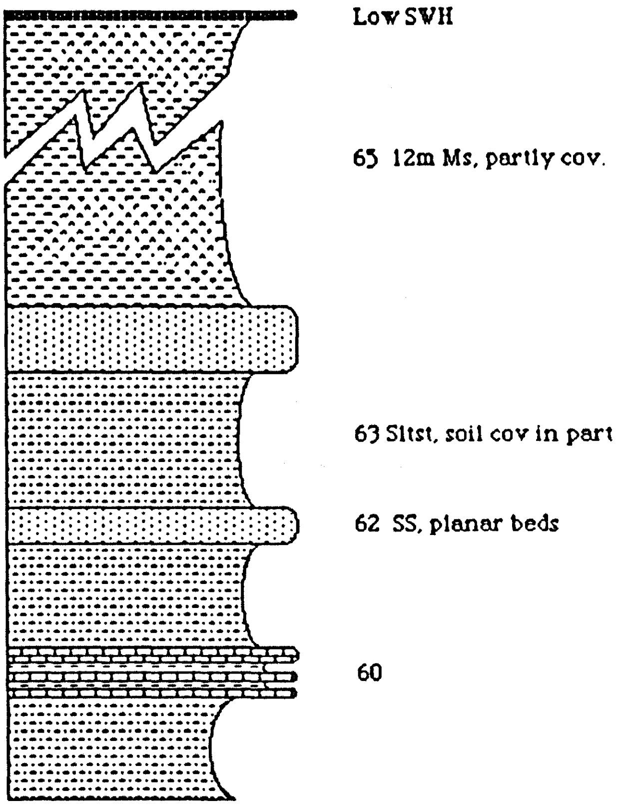


Figure 30 (Cont.). Bear Divide (BD) stratigraphic section.

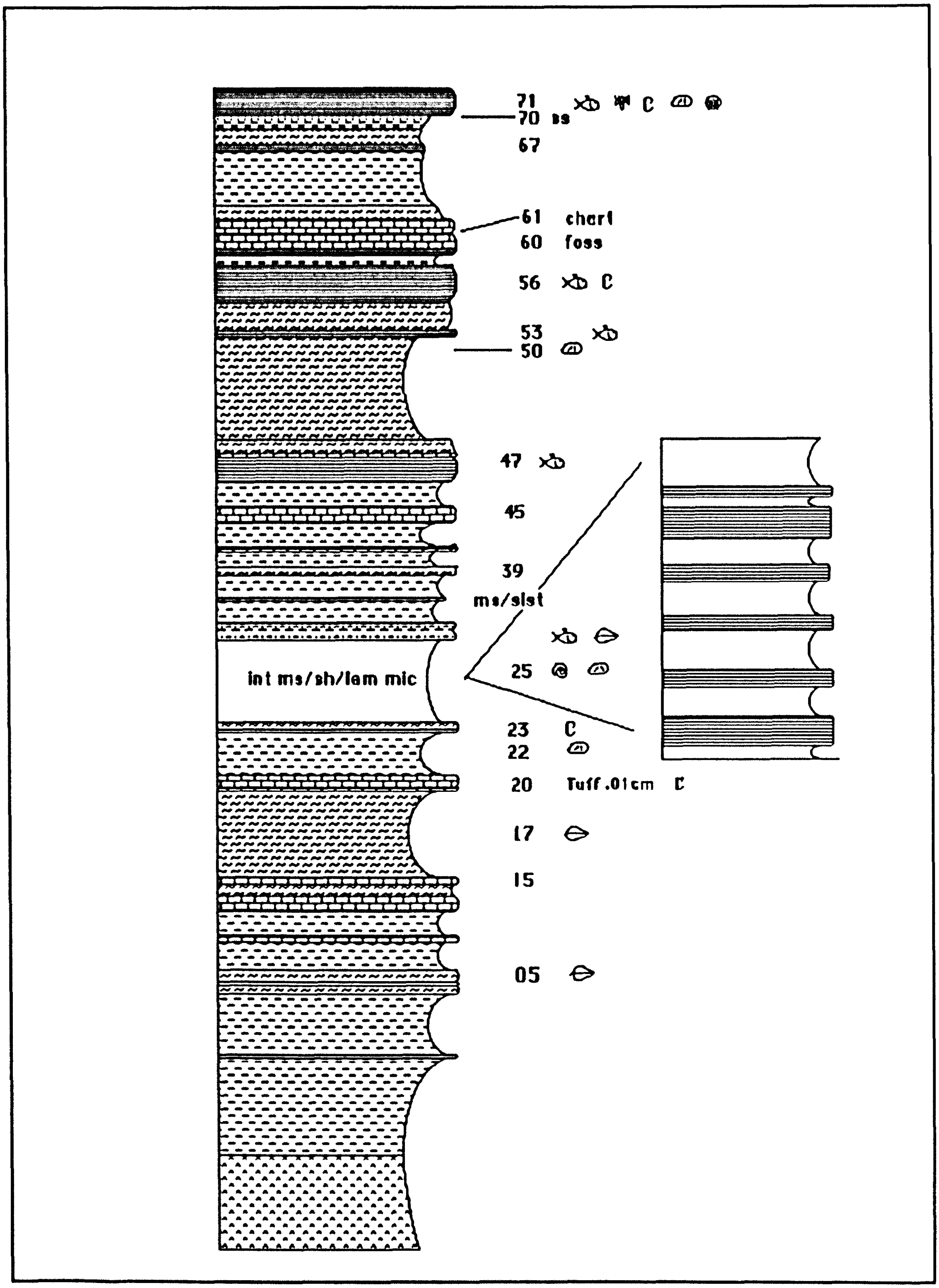


Figure 31. Chicken Creek (ChC) stratigraphic section.

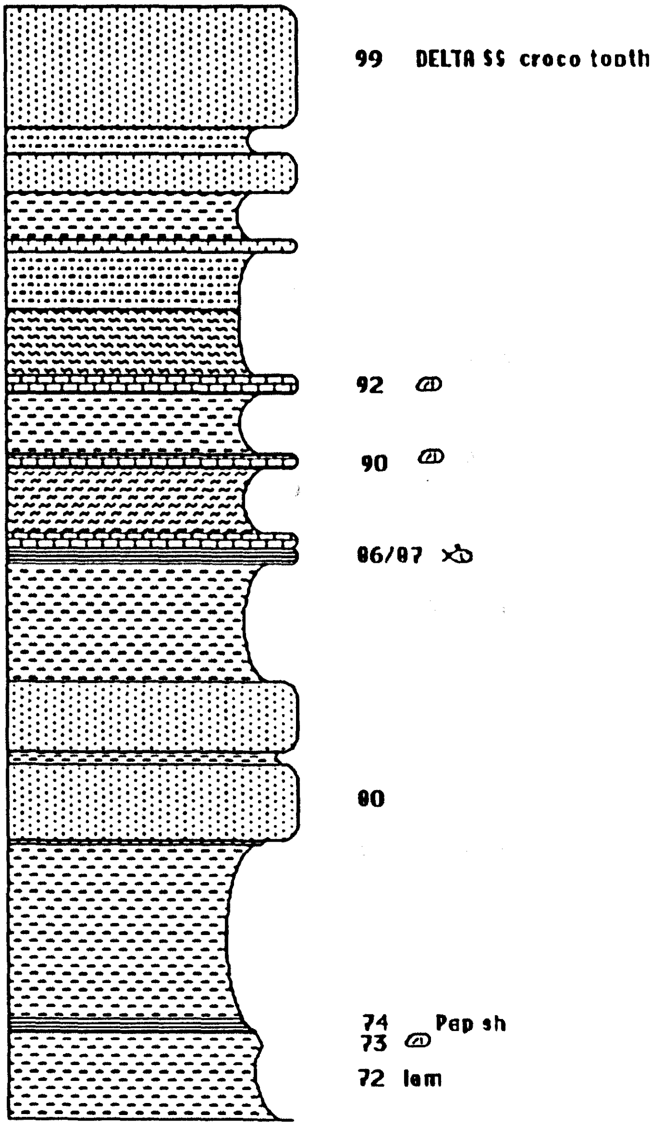


Figure 31 (Cont.). Chicken Creek (ChC) stratigraphic section.

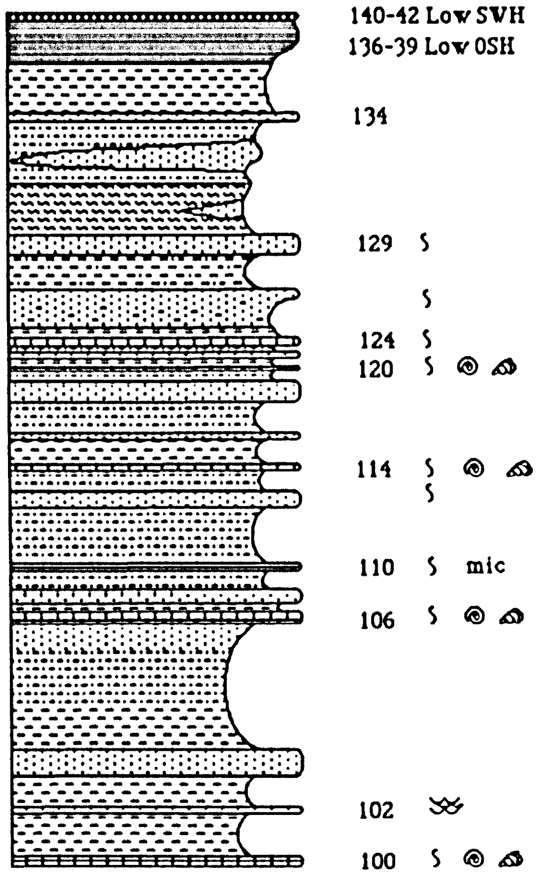


Figure 31 (Cont.). Chicken Creek (ChC) stratigraphic section.

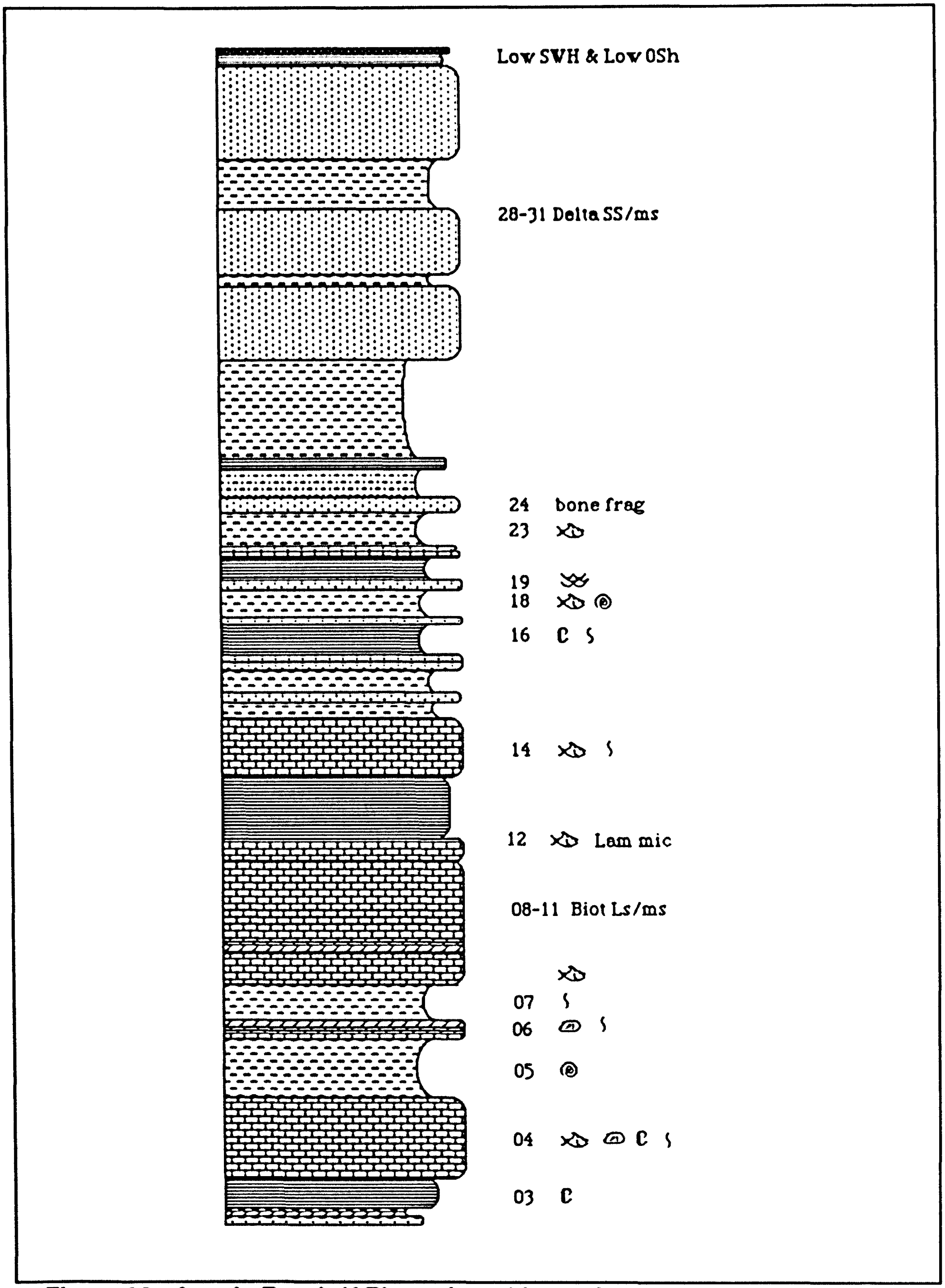


Figure 32. Angelo Ranch (AR) stratigraphic section.

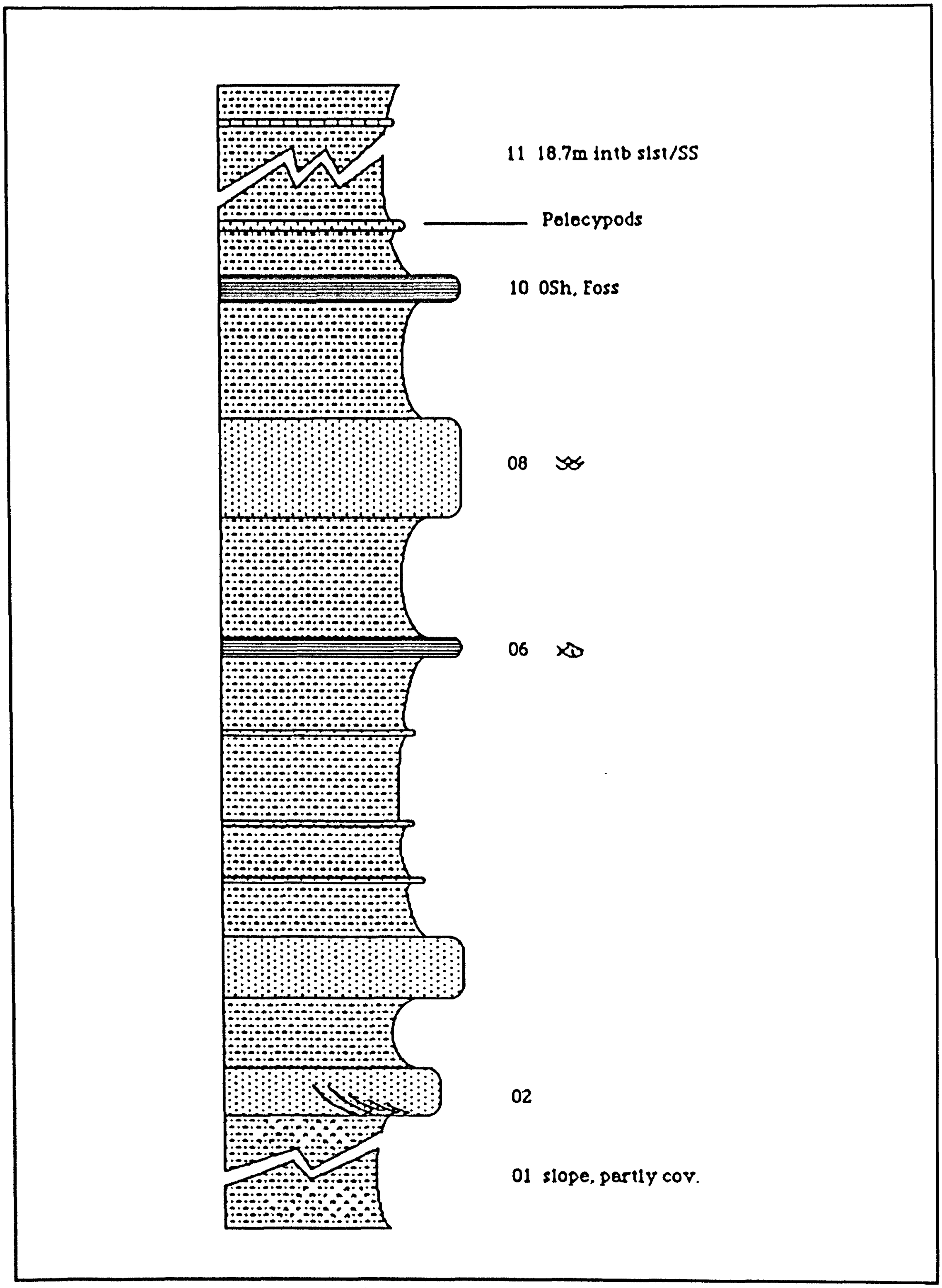


Figure 33. Carter Creek (CaC) stratigraphic section.

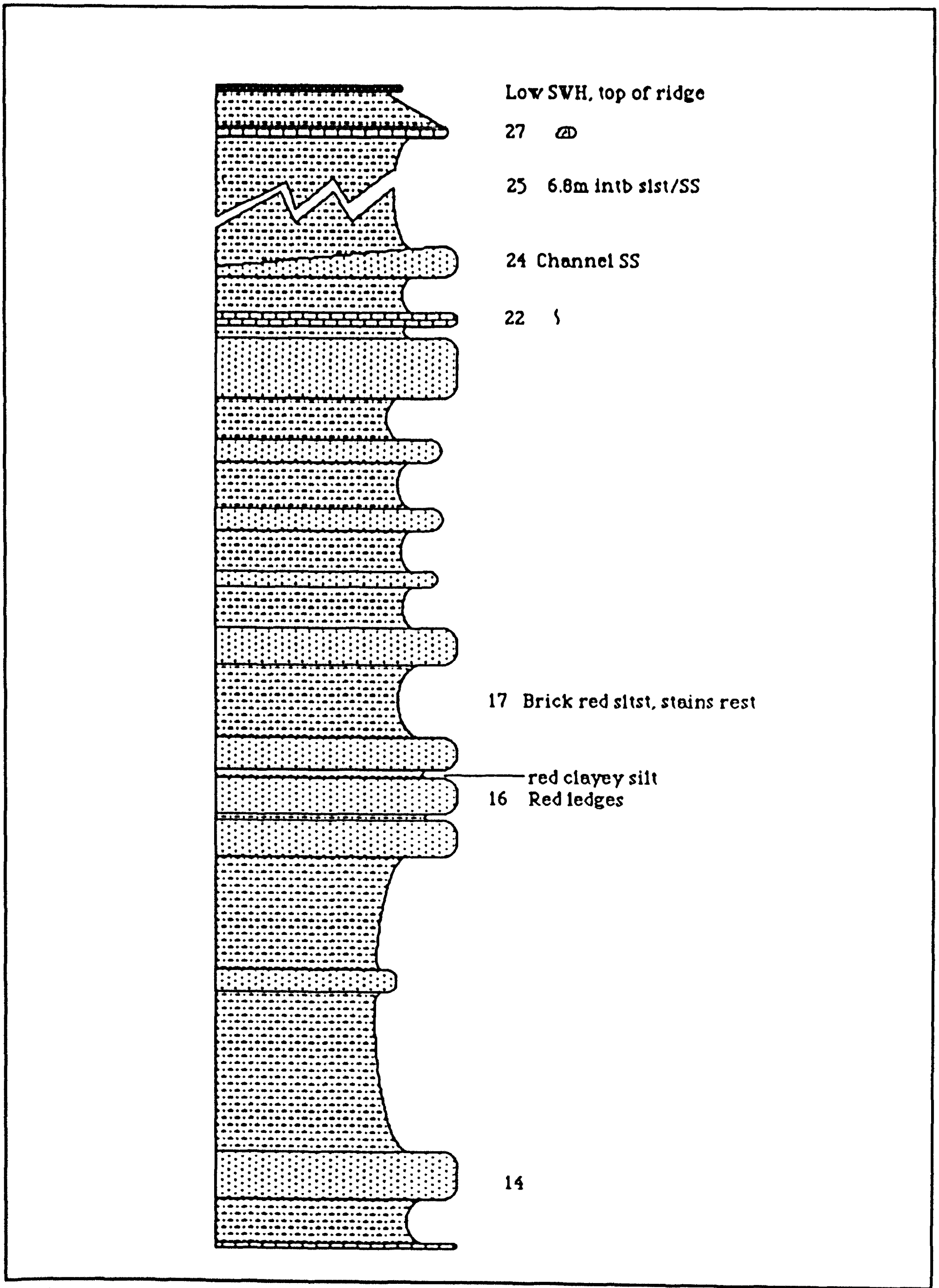


Figure 33 (Cont). Carter Creek (CaC) stratigraphic section.

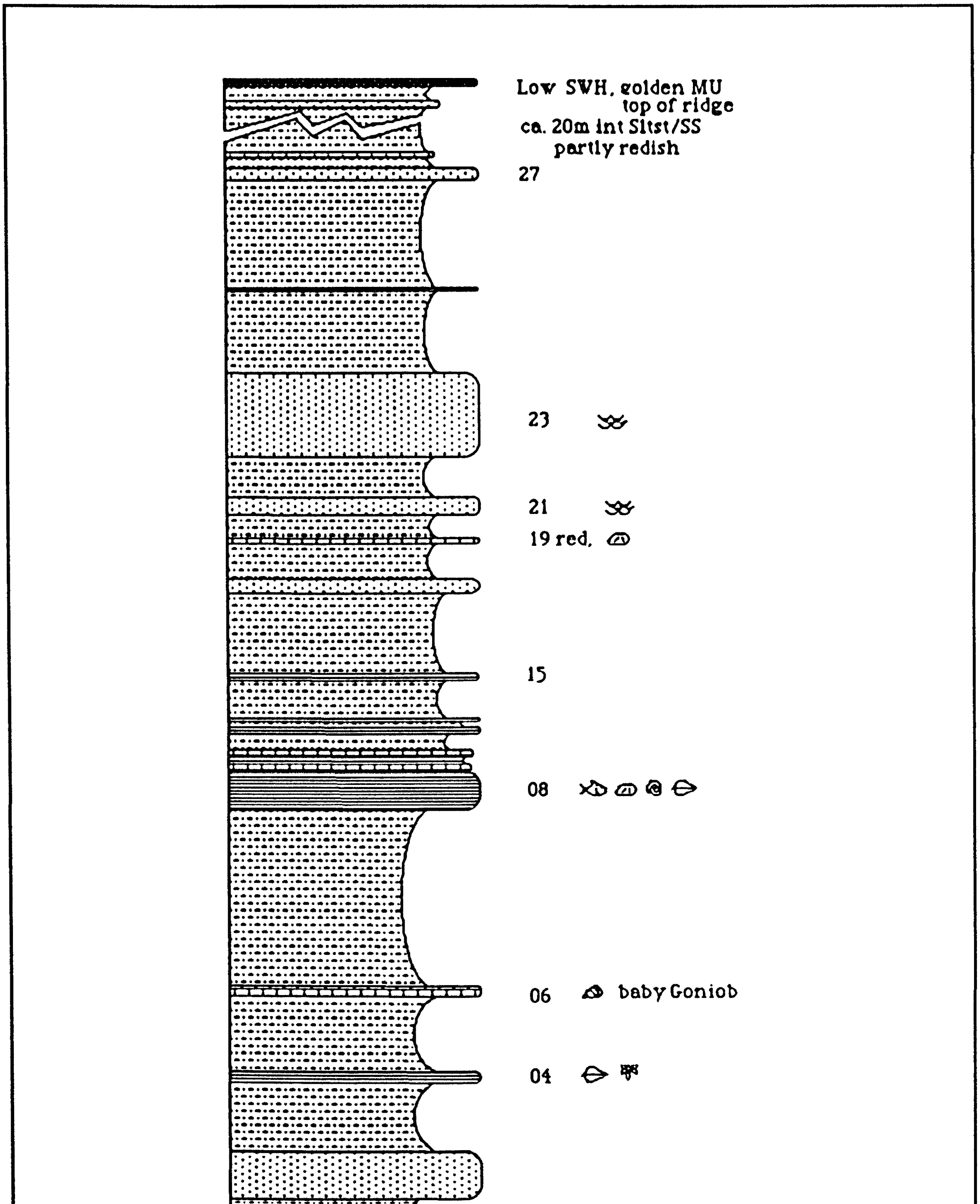


Figure 34. Sheep Creek (ShC) stratigraphic section.

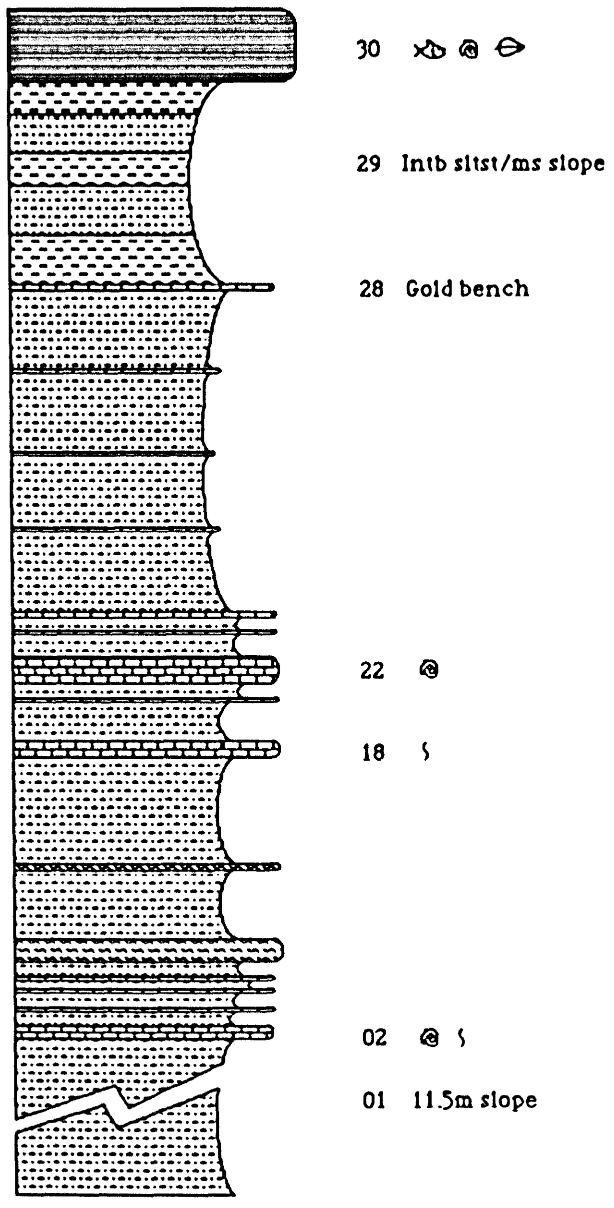


Figure 35. Sheep Creek/Little Muddy Creek (S/LMC) stratigraphic section.

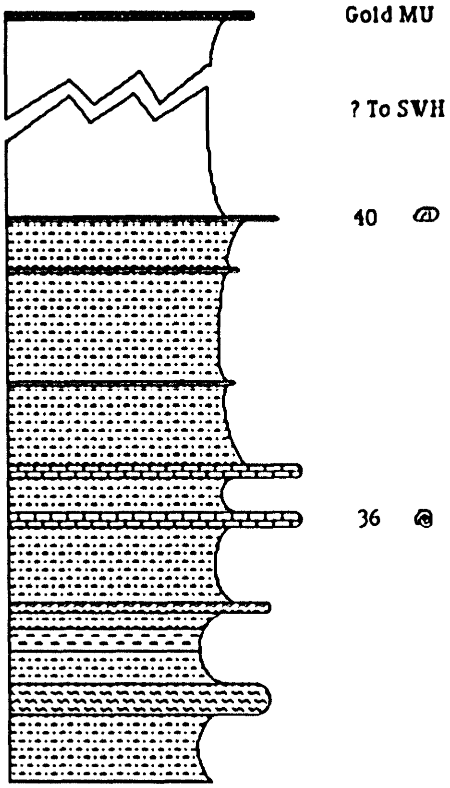


Figure 35 (Cont.). Sheep Creek/Little Muddy Creek (S/LMC) stratigraphic section.

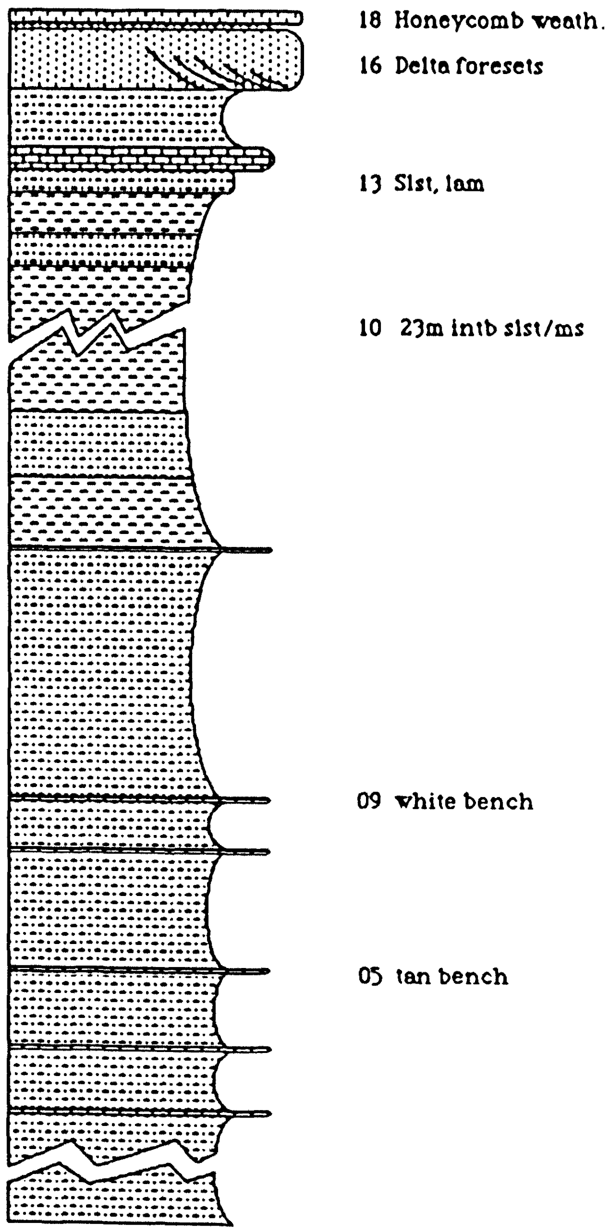


Figure 36. Hill Creek (HC) stratigraphic section.

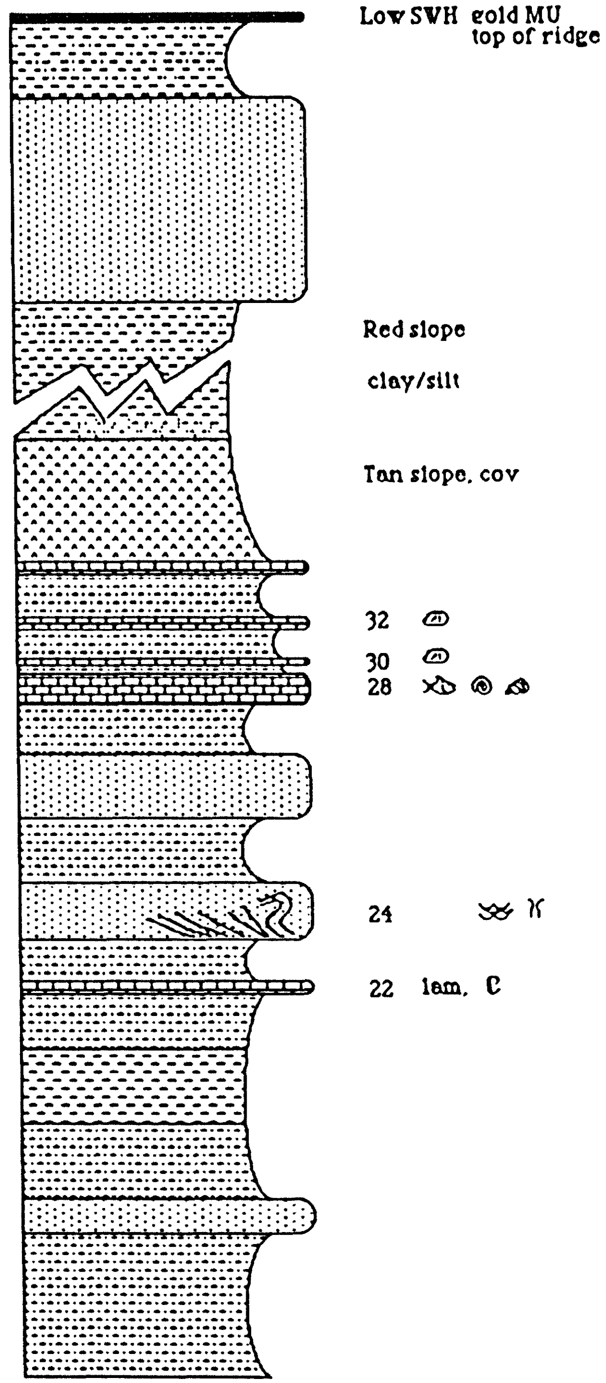


Figure 36 (Cont.). Hill Creek (HC) stratigraphic section.

APPENDIX 3

RESULTS OF X-RAY DIFFRACTION ANALYSES

Table 8

X-Ray Mineralogy

Sample		Calcite	Dolo-mite	Quartz	K-Spar	Plagio-clase	Anal-cime	Clays* <1%
ChC	01	7	(7)	25	7	-	50	Smect, Ill/mica
	03	10	-	30	-	-	55	Smect, Ill(<5)
	18	47	30	2-3	-	-	20	-
	25-IA	90	-	-	-	-	5-10	Smect.
	25-IC	70	(25)	-	-	-	5	Smect.(<2-3)
	25-ID	20	-	45	10	-	10	Smect., Ill(<10)
	25-IIA	25	-	30	-	-	40	Smect., Ill(<5)
	25-IIB	90	-	<5	-	-	-	Smect.(<5)
	25-IIC	30	10	50	-	-	-	Smect., Ill(<10)
	25-IID	95	-	<5	-	-	-	Smect.
	25-IIIA	95	-	<5	-	-	-	-
	25-IIIB	20	-	45	10	-	20	Smect./Ill.(<5)
	25-IIIC	60	<1	10	-	-	20	Smect.(<5)
	37	90	-	10	-	-	-	Smect.
	38	15	-	65	5	-	3-4	Ill.(10)
	47	80	(20	<5	-	-	-	-
	48	35	53	10	1	-	-	Smect.
	49	50	30	10	<1	-	2	Smect., Ill(5)
	69	70	(20)	10	<1	-	-	Ill.
	70	-	-	5	20	20	45	Mica (10)
	71	20	75 Aragonite	<2	-	-	-	-
	84	20	(10)	65	-	-	-	Ill(5)
	89	60	30	10	-	-	-	Smect.
BD	15A1	30	20	50	-	-	-	Smect., Ill(<5)
	15A2	15	75	10	-	-	-	Smect., Ill(<5)
	15B	60	-	35	-	-	-	Ill(<5)
	15C	35	(50)	10	-	-	-	Ill(<5)

*Clays: Smect.: Smectite; Ill.: Illite.

Table 8 (continued)

X-Ray Mineralogy

Sample		Calcite	Dolo-mite	Quartz	K-Spar	Plagio-clase	Anal-cime	Clays* <1%
CC	1A	14	(56)	28	-	-	-	-
	1B	25	55	13	6	-	-	-
	2	95	-	<5	-	-	-	-
	4	13	(6)	6	10	14	45	Ill., Chl./Kaol.
	5	22	(31)	8	9	-	30	-
	6	6	(8)	37	-	-	48	Ill.
	7	85	-	<1	3	-	11	-
	8	92	-	8	-	-	-	-
	9	60	38	<2	-	-	-	Chl./Kaol.
	11A	90	-	<5	-	-	-	Smect.(<5)
	24	68	16	7	-	-	<6	Gypsum(<2)
	25	6	-	40	4	-	50	Ill.
ShC	4	99	-	<1	-	-	-	-
	6	98	-	<2	-	-	-	-
	8	96	-	<4	-	-	-	-
	9	98	<2	-	-	-	-	Chl?
	19	57	(39)	3	-	<2	-	-
CaC	6	99	-	<1	-	-	-	-
	10A	97	-	<3	-	-	-	-
	10B	90	-	<5	-	<5	-	-
	12	83	(1)	14	<2	-	-	-
	22A	61	(23)	10	<3	-	-	Ill.,Chl./Kaol.
	22B	87	(6)	7	-	-	-	-
	27	96	2	2	-	-	-	-

*Clays: Smect.: Smectite; Ill.: Illite; Chl.: Chlorite; Kaol.: Kaolinite.

APPENDIX 4

TABULATION OF FACIES RELATIONSHIPS USING MARKOV CHAIN ANALYSIS

Table 9
Tabulation of Markov Chain Analysis: Fossil Butte Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0					1			1
Count	Slst		0				2		1	3
Matrix	MS			0		2	14		2	18
	Mic		3	1	0		1		1	6
Lower Bed	KPLMSil			4		0	1			5
	KPLM			11	2	2	0	3	11	29
	KRLM						3	0		3
	LS			3	3		9	1	0	16
	Col Tot	0	3	19	5	4	31	4	15	81

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS
Transition	SS	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Probability	Slst	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.33
Matrix	MS	0.00	0.00	0.00	0.00	0.11	0.78	0.00	0.11
	Mic	0.00	0.50	0.17	0.00	0.00	0.17	0.00	0.17
Lower Bed	KPLMSil	0.00	0.00	0.80	0.00	0.00	0.20	0.00	0.00
	KPLM	0.00	0.00	0.38	0.07	0.07	0.00	0.10	0.38
	KRLM	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
	LS	0.00	0.00	0.19	0.19	0.00	0.56	0.06	0.00

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	
Independent	SS	0.00	0.04	0.24	0.06	0.05	0.39	0.05	0.19	1.02
Trials Probab.	Slst	0.00	0.00	0.24	0.06	0.05	0.40	0.05	0.19	0.99
Matrix	MS	0.00	0.05	0.00	0.08	0.06	0.49	0.06	0.24	0.98
	Mic	0.00	0.04	0.25	0.00	0.05	0.41	0.05	0.20	1.00
Lower Bed	KPLMSil	0.00	0.04	0.25	0.07	0.00	0.41	0.05	0.20	1.02
	KPLM	0.00	0.06	0.37	0.10	0.08	0.00	0.08	0.29	0.98
	KRLM	0.00	0.04	0.24	0.06	0.05	0.40	0.00	0.19	0.98
	LS	0.00	0.05	0.29	0.08	0.06	0.48	0.06	0.00	1.02

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS
Difference	SS	0.00	-0.04	-0.24	-0.06	-0.05	0.61	-0.05	-0.19
Matrix	Slst	0.00	0.00	-0.24	-0.06	-0.05	0.27	-0.05	0.14
	MS	0.00	-0.05	0.00	-0.08	0.05	0.29	-0.06	-0.13
	Mic	0.00	0.46	-0.08	0.00	-0.05	-0.24	-0.05	-0.03
Lower Bed	KPLMSil	0.00	-0.04	0.55	-0.07	0.00	-0.21	-0.05	-0.20
	KPLM	0.00	-0.06	0.01	-0.03	-0.01	0.00	0.02	0.09
	KRLM	0.00	-0.04	-0.24	-0.06	-0.05	0.60	0.00	-0.19
	LS	0.00	-0.05	-0.10	0.11	-0.06	0.08	0.00	0.00

Table 10
Tabulation of Markov Chain Analysis: Fossil Ridge Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0		1						1
Count	Slst	1	0							1
Matrix	MS		1	0	4		9	3		17
	Mic			1	0		3	3	3	10
Lower Bed	KPLMSil					0	1			1
	KPLM			9	2	1	0	2	1	15
	KRLM			5	1		2	0	1	9
	LS			1	2		2		0	5
	Col Tot	1	1	17	9	1	17	8	5	$\boxed{59}$

Transition	SS	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Probability	Slst	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Matrix	MS	0.00	0.06	0.00	0.24	0.00	0.53	0.18	0.00
	Mic	0.00	0.00	0.10	0.00	0.00	0.30	0.30	0.30
Lower Bed	KPLMSil	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
	KPLM	0.00	0.00	0.60	0.13	0.07	0.00	0.13	0.07
	KRLM	0.00	0.00	0.56	0.11	0.00	0.22	0.00	0.11
	LS	0.00	0.00	0.20	0.40	0.00	0.40	0.00	0.00

Independent	SS	0.00	0.02	0.29	0.16	0.02	0.29	0.14	0.09	1.01
Trials Probab.	Slst	0.02	0.00	0.29	0.16	0.02	0.29	0.14	0.09	1.01
Matrix	MS	0.02	0.02	0.00	0.21	0.02	0.40	0.19	0.12	0.98
	Mic	0.02	0.02	0.35	0.00	0.02	0.35	0.16	0.10	1.02
Lower Bed	KPLMSil	0.02	0.02	0.29	0.16	0.00	0.29	0.14	0.09	1.01
	KPLM	0.02	0.02	0.39	0.20	0.02	0.00	0.18	0.11	0.94
	KRLM	0.02	0.02	0.34	0.18	0.02	0.34	0.00	0.10	1.02
	LS	0.02	0.02	0.31	0.17	0.02	0.31	0.15	0.00	1.00

Difference	SS	0.00	-0.02	0.71	-0.16	-0.02	-0.29	-0.14	-0.09
Matrix	Slst	0.98	0.00	-0.29	-0.16	-0.02	-0.29	-0.14	-0.09
	MS	-0.02	0.04	0.00	0.03	-0.02	0.13	-0.01	-0.12
	Mic	-0.02	-0.02	-0.25	0.00	-0.02	-0.05	0.14	0.20
Lower Bed	KPLMSil	-0.02	-0.02	-0.29	-0.16	0.00	0.71	-0.14	-0.09
	KPLM	-0.02	-0.02	0.21	-0.07	0.05	0.00	-0.05	-0.04
	KRLM	-0.02	-0.02	0.22	-0.07	-0.02	-0.12	0.00	0.01
	LS	-0.02	-0.02	-0.11	0.23	-0.02	0.09	-0.15	0.00

Table 11
Tabulation of Markov Chain Analysis: Clear Creek Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0	2							2
Count	Slst	2	0	2	6		3			13
Matrix	MS		3	0	7	1	8	2		21
	Mic		6	6	0	1	1	3		17
Lower Bed	KPLMSil			6		0	1			7
	KPLM		3	7	1	2	0		1	14
	KRLM			1	3		1	0		5
	LS						1		0	1
	Col Tot	2	14	22	17	4	15	5	1	80
Transition	SS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Probability	Slst	0.15	0.00	0.15	0.46	0.00	0.23	0.00	0.00	
Matrix	MS	0.00	0.14	0.00	0.33	0.05	0.38	0.10	0.00	
	Mic	0.00	0.35	0.35	0.00	0.06	0.06	0.18	0.00	
Lower Bed	KPLMSil	0.00	0.00	0.86	0.00	0.00	0.14	0.00	0.00	
	KPLM	0.00	0.21	0.50	0.07	0.14	0.00	0.00	0.07	
	KRLM	0.00	0.00	0.20	0.60	0.00	0.20	0.00	0.00	
	LS	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	
Independent	SS	0.00	0.18	0.28	0.22	0.05	0.19	0.06	0.01	0.99
Trials Probab.	Slst	0.03	0.00	0.33	0.25	0.06	0.22	0.07	0.01	0.97
Matrix	MS	0.03	0.24	0.00	0.29	0.07	0.25	0.08	0.02	0.98
	Mic	0.03	0.22	0.35	0.00	0.06	0.24	0.08	0.02	1.00
Lower Bed	KPLMSil	0.03	0.19	0.30	0.23	0.00	0.21	0.07	0.01	1.04
	KPLM	0.03	0.21	0.33	0.26	0.06	0.00	0.08	0.02	0.99
	KRLM	0.03	0.19	0.29	0.23	0.05	0.20	0.00	0.01	1.00
	LS	0.03	0.18	0.28	0.22	0.05	0.19	0.06	0.00	1.01
Difference	SS	0.00	0.82	-0.28	-0.22	-0.05	-0.19	-0.06	-0.01	
Matrix	Slst	0.12	0.00	-0.18	0.21	-0.06	0.01	-0.07	-0.01	
	MS	-0.03	-0.10	0.00	0.04	-0.02	0.13	0.02	-0.02	
	Mic	-0.03	0.13	0.00	0.00	0.00	-0.18	0.10	-0.02	
Lower Bed	KPLMSil	-0.03	-0.19	0.56	-0.23	0.00	-0.07	-0.07	-0.01	
	KPLM	-0.03	0.00	0.17	-0.19	0.08	0.00	-0.08	0.05	
	KRLM	-0.03	-0.19	-0.09	0.37	-0.05	0.00	0.00	-0.01	
	LS	-0.03	-0.18	-0.28	-0.22	-0.05	0.81	-0.06	0.00	

Table 12
Tabulation of Markov Chain Analysis: Bear Divide Section

	Upper Bed	SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition Count Matrix	SS	0	4	1						5
	Slst	5	0	5				1	4	15
	MS		8	0	6		15		6	35
	Mic			7	0		4	2	3	16
Lower Bed	KPLMSil			1	1	0	3			5
	KPLM		2	13	2	3	0		4	24
	KRLM		1	1			1	0		3
	LS		2	7	7	2			0	18
	Col Tot	5	17	35	16	5	23	3	17	$\boxed{121}$

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS
Transition Probability Matrix	SS	0.00	0.80	0.20	0.00	0.00	0.00	0.00	0.00
	Slst	0.33	0.00	0.33	0.00	0.00	0.00	0.07	0.27
	MS	0.00	0.23	0.00	0.17	0.00	0.43	0.00	0.17
	Mic	0.00	0.00	0.44	0.00	0.00	0.25	0.13	0.19
Lower Bed	KPLMSil	0.00	0.00	0.20	0.20	0.00	0.60	0.00	0.00
	KPLM	0.00	0.08	0.54	0.08	0.13	0.00	0.00	0.17
	KRLM	0.00	0.33	0.33	0.00	0.00	0.33	0.00	0.00
	LS	0.00	0.11	0.39	0.39	0.11	0.00	0.00	0.00

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	
Independent Trials Probab. Matrix	SS	0.00	0.15	0.30	0.14	0.04	0.20	0.03	0.15	1.01
	Slst	0.05	0.00	0.33	0.15	0.05	0.22	0.03	0.16	0.99
	MS	0.06	0.20	0.00	0.19	0.06	0.27	0.03	0.20	1.01
	Mic	0.05	0.16	0.33	0.00	0.05	0.22	0.03	0.16	1.00
Lower Bed	KPLMSil	0.04	0.15	0.30	0.14	0.00	0.20	0.03	0.15	1.01
	KPLM	0.05	0.18	0.36	0.16	0.05	0.00	0.03	0.18	1.01
	KRLM	0.04	0.14	0.30	0.14	0.04	0.19	0.00	0.14	0.99
	LS	0.05	0.17	0.34	0.16	0.05	0.22	0.03	0.00	1.02

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS
Difference Matrix	SS	0.00	0.65	-0.10	-0.14	-0.04	-0.20	-0.03	-0.15
	Slst	0.28	0.00	0.00	-0.15	-0.05	-0.22	0.04	0.11
	MS	-0.06	0.03	0.00	-0.02	-0.06	0.16	-0.03	-0.03
	Mic	-0.05	-0.16	0.11	0.00	-0.05	0.03	0.10	0.03
Lower Bed	KPLMSil	-0.04	-0.15	-0.10	0.06	0.00	0.40	-0.03	-0.15
	KPLM	-0.05	-0.10	0.18	-0.08	0.08	0.00	-0.03	-0.01
	KRLM	-0.04	0.19	0.03	-0.14	-0.04	0.14	0.00	-0.14
	LS	-0.05	-0.06	0.05	0.23	0.06	-0.22	-0.03	0.00

Table 13
Tabulation of Markov Chain Analysis: Chicken Creek Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0	7	6	1				2	16
Count	Slst	4	0	6					5	15
Matrix	MS	11	7	0	11	1	19		5	54
	Mic			13	0		2	2	3	20
Lower Bed	KPLMSil			2		0				2
	KPLM			16	2	1	0	3	3	25
	KRLM			2	1		2	0		5
	LS	1	1	9	5		2		0	18
	Col Tot	16	15	54	20	2	25	5	18	$\boxed{155}$

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS
Transition	SS	0.00	0.44	0.38	0.06	0.00	0.00	0.00	0.13
Probability	Slst	0.27	0.00	0.40	0.00	0.00	0.00	0.00	0.33
Matrix	MS	0.20	0.13	0.00	0.20	0.02	0.35	0.00	0.09
	Mic	0.00	0.00	0.65	0.00	0.00	0.10	0.10	0.15
Lower Bed	KPLMSil	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
	KPLM	0.00	0.00	0.64	0.08	0.04	0.00	0.12	0.12
	KRLM	0.00	0.00	0.40	0.20	0.00	0.40	0.00	0.00
	LS	0.06	0.06	0.50	0.28	0.00	0.11	0.00	0.00

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	
Independent	SS	0.00	0.11	0.39	0.14	0.01	0.18	0.04	0.13	1.00
Trials Probab.	Slst	0.11	0.00	0.39	0.14	0.01	0.18	0.04	0.13	1.00
Matrix	MS	0.16	0.15	0.00	0.20	0.02	0.25	0.05	0.18	1.01
	Mic	0.12	0.11	0.40	0.00	0.01	0.19	0.04	0.13	1.00
Lower Bed	KPLMSil	0.10	0.10	0.35	0.13	0.00	0.16	0.03	0.12	0.99
	KPLM	0.12	0.12	0.42	0.15	0.02	0.00	0.04	0.14	1.01
	KRLM	0.11	0.10	0.36	0.13	0.01	0.17	0.00	0.12	1.00
	LS	0.12	0.11	0.39	0.15	0.01	0.18	0.04	0.00	1.00

		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS
Difference	SS	0.00	0.33	-0.01	-0.08	-0.01	-0.18	-0.04	0.00
Matrix	Slst	0.16	0.00	0.01	-0.14	-0.01	-0.18	-0.04	0.20
	MS	0.04	-0.02	0.00	0.00	0.00	0.10	-0.05	-0.09
	Mic	-0.12	-0.11	0.25	0.00	-0.01	-0.09	0.06	0.02
Lower Bed	KPLMSil	-0.10	-0.10	0.65	-0.13	0.00	-0.16	-0.03	-0.12
	KPLM	-0.12	-0.12	0.22	-0.07	0.02	0.00	0.08	-0.02
	KRLM	-0.11	-0.10	0.04	0.07	-0.01	0.23	0.00	-0.12
	LS	-0.06	-0.05	0.11	0.13	-0.01	-0.07	-0.04	0.00

Table 14
Tabulation of Markov Chain Analysis: Angelo Ranch Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0	1	5			2			8
Count	Slst		0				1			1
Matrix	MS	4		0	1	2	4		2	13
	Mic	1			0		1		3	5
Lower Bed	KPLMSil	1			1	0	1			3
	KPLM	1		4	1	1	0		3	10
	KRLM							0		0
	LS	1		4	2		1		0	8
	Col Tot	8	1	13	5	3	10	0	8	$\boxed{48}$

Transition	SS	0.00	0.13	0.63	0.00	0.00	0.25	0.00	0.00
Probability	Slst	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Matrix	MS	0.31	0.00	0.00	0.08	0.15	0.31	0.00	0.15
	Mic	0.20	0.00	0.00	0.00	0.00	0.20	0.00	0.60
Lower Bed	KPLMSil	0.33	0.00	0.00	0.33	0.00	0.33	0.00	0.00
	KPLM	0.10	0.00	0.40	0.10	0.10	0.00	0.00	0.30
	KRLM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	LS	0.13	0.00	0.50	0.25	0.00	0.13	0.00	0.00

Independent	SS	0.00	0.03	0.33	0.13	0.08	0.25	0.00	0.20	1.02
Trials Probab.	Slst	0.17	0.00	0.28	0.11	0.06	0.21	0.00	0.17	1.00
Matrix	MS	0.23	0.03	0.00	0.14	0.09	0.29	0.00	0.23	1.01
	Mic	0.19	0.02	0.30	0.00	0.07	0.23	0.00	0.19	1.00
Lower Bed	KPLMSil	0.18	0.02	0.29	0.11	0.00	0.22	0.00	0.18	1.00
	KPLM	0.21	0.03	0.34	0.13	0.08	0.00	0.00	0.21	1.00
	KRLM	0.17	0.02	0.27	0.10	0.06	0.21	0.00	0.17	1.00
	LS	0.20	0.03	0.33	0.13	0.08	0.25	0.00	0.00	1.02

Difference	SS	0.00	0.10	0.30	-0.13	-0.08	0.00	0	-0.20
Matrix	Slst	-0.17	0.00	-0.28	-0.11	-0.06	0.79	0.00	-0.17
	MS	0.08	-0.03	0.00	-0.06	0.06	0.02	0.00	-0.08
	Mic	0.01	-0.02	-0.30	0.00	-0.07	-0.03	0.00	0.41
Lower Bed	KPLMSil	0.15	-0.02	-0.29	0.22	0.00	0.11	0.00	-0.18
	KPLM	-0.11	-0.03	0.06	-0.03	0.02	0.00	0.00	0.09
	KRLM	-0.17	-0.02	-0.27	-0.10	-0.06	-0.21	0.00	-0.17
	LS	-0.07	-0.03	0.17	0.12	-0.08	-0.12	0.00	0.00

Table 15
Tabulation of Markov Chain Analysis: Carter Creek Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0	26							26
Count	Slst	26	0		1	1			2	30
Matrix	MS			0						0
	Mic				0				1	1
Lower Bed	KPLMSil		1			0				1
	KPLM		1				0	1		2
	KRLM						1	0		1
	LS		2						0	2
	Col Tot	26	30	0	1	1	1	1	3	63

Transition	SS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Probability	Slst	0.87	0.00	0.00	0.03	0.03	0.00	0.00	0.07	
Matrix	MS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	Mic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
Lower Bed	KPLMSil	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
	KPLM	0.00	0.50	0.00	0.00	0.00	0.00	0.50	0.00	
	KRLM	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	
	LS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	

Independent	SS	0.00	0.81	0.00	0.03	0.03	0.03	0.03	0.08	1.01
Trials Probab.	Slst	0.79	0.00	0.00	0.03	0.03	0.03	0.03	0.09	1.00
Matrix	MS	0.41	0.48	0.00	0.02	0.02	0.02	0.02	0.05	1.02
	Mic	0.42	0.48	0.00	0.00	0.02	0.02	0.02	0.05	1.01
Lower Bed	KPLMSil	0.42	0.48	0.00	0.02	0.00	0.02	0.02	0.05	1.01
	KPLM	0.43	0.49	0.00	0.02	0.02	0.00	0.02	0.05	1.03
	KRLM	0.42	0.48	0.00	0.02	0.02	0.02	0.00	0.05	1.01
	LS	0.43	0.49	0.00	0.02	0.02	0.02	0.02	0.00	1.00

Difference	SS	0.00	0.19	0.00	-0.03	-0.03	-0.03	-0.03	-0.08	
Matrix	Slst	0.08	0.00	0.00	0.00	0.00	-0.03	-0.03	-0.02	
	MS	-0.41	-0.48	0.00	-0.02	-0.02	-0.02	-0.02	-0.05	
	Mic	-0.42	-0.48	0.00	0.00	-0.02	-0.02	-0.02	0.95	
Lower Bed	KPLMSil	-0.42	0.52	0.00	-0.02	0.00	-0.02	-0.02	-0.05	
	KPLM	-0.43	0.01	0.00	-0.02	-0.02	0.00	0.48	-0.05	
	KRLM	-0.42	-0.48	0.00	-0.02	-0.02	0.98	0.00	-0.05	
	LS	-0.43	0.51	0.00	-0.02	-0.02	-0.02	-0.02	0.00	

Table 16
Tabulation of Markov Chain Analysis: Sheep Creek Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0	11							11
Count	Slst	11	0						3	14
Matrix	MS			0			15			15
	Mic				0		4			4
Lower Bed	KPLMSil					0	3			3
	KPLM		4		1		0	1		6
	KRLM				1		1	0		2
	LS		3						0	3
	Col Tot	11	18	0	2	0	23	1	3	58
Transition	SS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Probability	Slst	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.21	
Matrix	MS	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	
	Mic	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	
Lower Bed	KPLMSil	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	
	KPLM	0.00	0.67	0.00	0.17	0.00	0.00	0.17	0.00	
	KRLM	0.00	0.00	0.00	0.50	0.00	0.50	0.00	0.00	
	LS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Independent	SS	0.00	0.38	0.00	0.04	0.00	0.49	0.02	0.06	0.99
Trials Probab.	Slst	0.25	0.00	0.00	0.05	0.00	0.52	0.02	0.07	0.91
Matrix	MS	0.26	0.42	0.00	0.05	0.00	0.53	0.02	0.07	1.35
	Mic	0.20	0.33	0.00	0.00	0.00	0.43	0.02	0.06	1.04
Lower Bed	KPLMSil	0.20	0.33	0.00	0.04	0.00	0.42	0.02	0.05	1.06
	KPLM	0.21	0.35	0.00	0.04	0.00	0.00	0.02	0.06	0.68
	KRLM	0.20	0.32	0.00	0.04	0.00	0.41	0.00	0.05	1.02
	LS	0.20	0.33	0.00	0.04	0.00	0.42	0.02	0.00	1.01
Difference	SS	0.00	0.62	0.00	-0.04	0.00	-0.49	-0.02	-0.06	
Matrix	Slst	0.54	0.00	0.00	-0.05	0.00	-0.52	-0.02	0.14	
	MS	-0.26	-0.42	0.00	-0.05	0.00	0.47	-0.02	-0.07	
	Mic	-0.20	-0.33	0.00	0.00	0.00	0.57	-0.02	-0.06	
Lower Bed	KPLMSil	-0.20	-0.33	0.00	-0.04	0.00	0.58	-0.02	-0.05	
	KPLM	-0.21	0.32	0.00	0.13	0.00	0.00	0.15	-0.06	
	KRLM	-0.20	-0.32	0.00	0.46	0.00	0.09	0.00	-0.05	
	LS	-0.20	0.67	0.00	-0.04	0.00	-0.42	-0.02	0.00	

Table 17
Tabulation of Markov Chain Analysis: SheepCreek/ Little Muddy Creek Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0								0
Count	Slst		0	4	7		2		17	30
Matrix	MS		2	0	1		1			4
	Mic		8		0					8
Lower Bed	KPLMSil					0				0
	KPLM		2				0	1		3
	KRLM		1					0		1
	LS		16						0	16
	Col Tot	0	29	4	8	0	3	1	17	$\boxed{62}$
Transition	SS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Probability	Slst	0.00	0.00	0.13	0.23	0.00	0.07	0.00	0.57	
Matrix	MS	0.00	0.50	0.00	0.25	0.00	0.25	0.00	0.00	
	Mic	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Lower Bed	KPLMSil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	KPLM	0.00	0.67	0.00	0.00	0.00	0.00	0.33	0.00	
	KRLM	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
	LS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Independent	SS	0.00	0.47	0.06	0.13	0.00	0.05	0.02	0.27	1.00
Trials Probab.	Slst	0.00	0.00	0.13	0.25	0.00	0.09	0.03	0.53	1.03
Matrix	MS	0.00	0.50	0.00	0.14	0.00	0.05	0.02	0.29	1.00
	Mic	0.00	0.54	0.07	0.00	0.00	0.06	0.02	0.31	1.00
Lower Bed	KPLMSil	0.00	0.47	0.06	0.13	0.00	0.05	0.02	0.27	1.00
	KPLM	0.00	0.49	0.07	0.14	0.00	0.00	0.02	0.29	1.01
	KRLM	0.00	0.48	0.07	0.13	0.00	0.05	0.00	0.28	1.01
	LS	0.00	0.63	0.09	0.17	0.00	0.07	0.02	0.00	0.98
Difference	SS	0.00	-0.47	-0.06	-0.13	0.00	-0.05	-0.02	-0.27	
Matrix	Slst	0.00	0.00	0.00	-0.02	0.00	-0.02	-0.03	0.04	
	MS	0.00	0.00	0.00	0.11	0.00	0.20	-0.02	-0.29	
	Mic	0.00	0.46	-0.07	0.00	0.00	-0.06	-0.02	-0.31	
Lower Bed	KPLMSil	0.00	-0.47	-0.06	-0.13	0.00	-0.05	-0.02	-0.27	
	KPLM	0.00	0.18	-0.07	-0.14	0.00	0.00	0.31	-0.29	
	KRLM	0.00	0.52	-0.07	-0.13	0.00	-0.05	0.00	-0.28	
	LS	0.00	0.37	-0.09	-0.17	0.00	-0.07	-0.02	0.00	

Table 18
Tabulation of Markov Chain Analysis: Hill Creek Section

		Upper Bed								
		SS	Slst	MS	Mic	KPLMSil	KPLM	KRLM	LS	Row Tot
Transition	SS	0	8							8
Count	Slst	8	0	2					10	20
Matrix	MS			0			1		1	2
	Mic				0					0
Lower Bed	KPLMSil					0				0
	KPLM						0		1	1
	KRLM							0		0
	LS		12						0	12
	Col Tot	8	20	2	0	0	1	0	12	43
Transition	SS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Probability	Slst	0.40	0.00	0.10	0.00	0.00	0.00	0.00	0.50	
Matrix	MS	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	
	Mic	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Lower Bed	KPLMSil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	KPLM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	
	KRLM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	LS	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	
Independent	SS	0.00	0.57	0.06	0.00	0.00	0.03	0.00	0.34	1.00
Trials Probab.	Slst	0.35	0.00	0.09	0.00	0.00	0.04	0.00	0.52	1.00
Matrix	MS	0.20	0.49	0.00	0.00	0.00	0.02	0.00	0.29	1.00
	Mic	0.19	0.47	0.05	0.00	0.00	0.02	0.00	0.28	1.01
Lower Bed	KPLMSil	0.19	0.47	0.05	0.00	0.00	0.02	0.00	0.28	1.01
	KPLM	0.19	0.48	0.05	0.00	0.00	0.00	0.00	0.29	1.01
	KRLM	0.19	0.47	0.05	0.00	0.00	0.02	0.00	0.28	1.01
	LS	0.26	0.65	0.06	0.00	0.00	0.03	0.00	0.00	1.00
Difference	SS	0.00	0.43	-0.06	0.00	0.00	-0.03	0	-0.34	
Matrix	Slst	0.05	0.00	0.01	0.00	0.00	-0.04	0.00	-0.02	
	MS	-0.20	-0.49	0.00	0.00	0.00	0.48	0.00	0.21	
	Mic	-0.19	-0.47	-0.05	0.00	0.00	-0.02	0.00	-0.28	
Lower Bed	KPLMSil	-0.19	-0.47	-0.05	0.00	0.00	-0.02	0.00	-0.28	
	KPLM	-0.19	-0.48	-0.05	0.00	0.00	0.00	0.00	0.71	
	KRLM	-0.19	-0.47	-0.05	0.00	0.00	-0.02	0.00	-0.28	
	LS	-0.26	0.35	-0.06	0.00	0.00	-0.03	0.00	0.00	

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