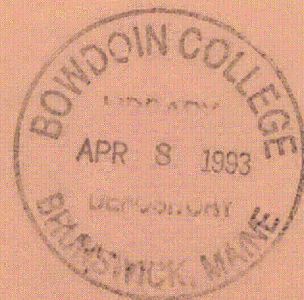
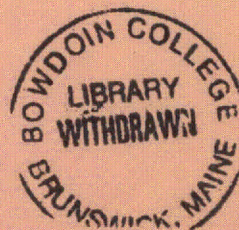
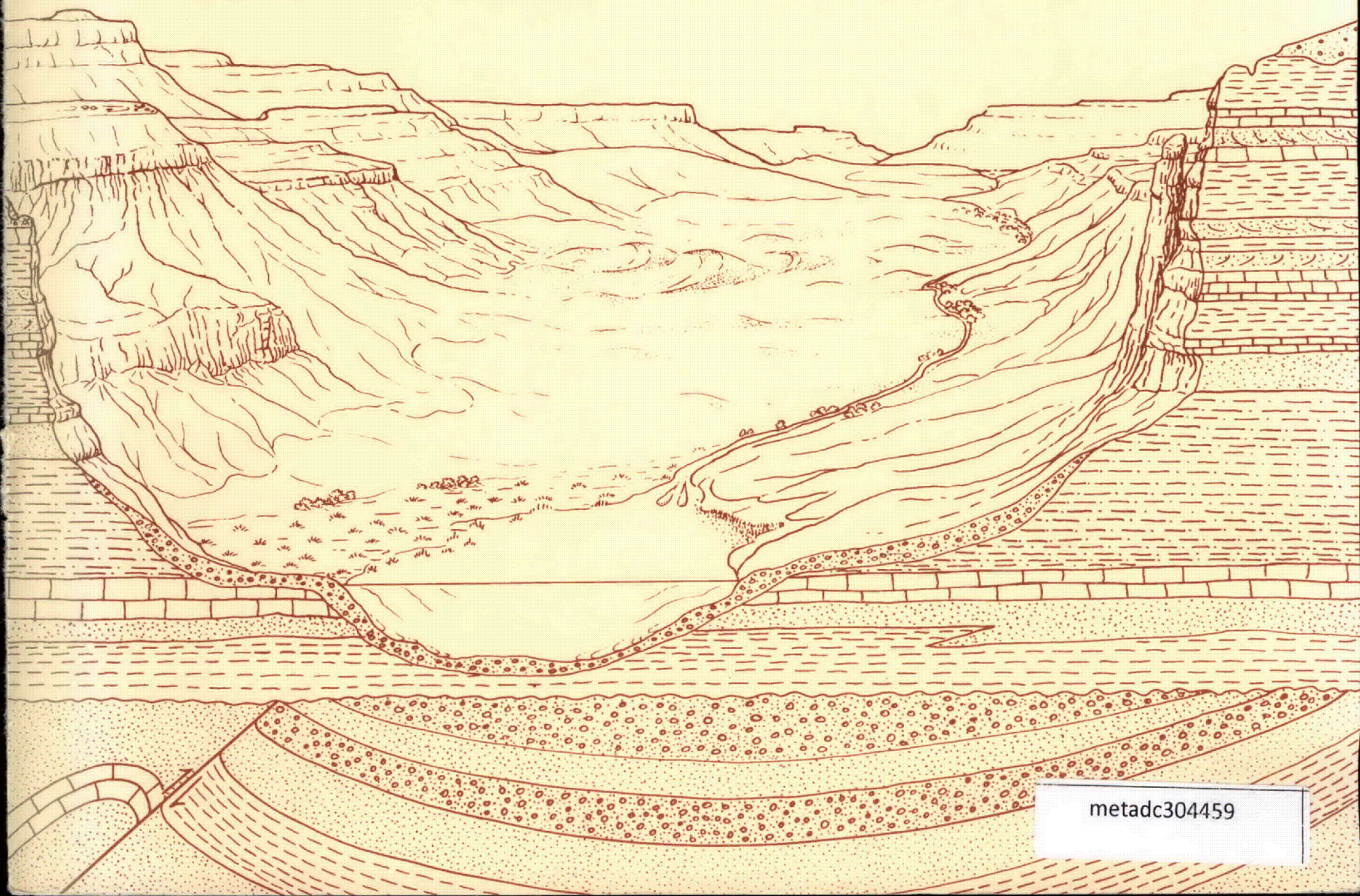


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# Stratigraphy of the Eocene Part of the Green River Formation in the South-Central Part of the Uinta Basin, Utah



U.S. GEOLOGICAL SURVEY BULLETIN 1787-BB



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Chapter BB

# Stratigraphy of the Eocene Part of the Green River Formation in the South-Central Part of the Uinta Basin, Utah

By ROBERT R. REMY

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

U.S. GEOLOGICAL SURVEY BULLETIN 1787

EVOLUTION OF SEDIMENTARY BASINS—UINTA AND PICEANCE BASINS

U.S. DEPARTMENT OF THE INTERIOR  
MANUEL LUJAN, JR., Secretary



U.S. GEOLOGICAL SURVEY  
Dallas L. Peck, Director

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# Stratigraphy of the Eocene Part of the Green River Formation in the South-Central Part of the Uinta Basin, Utah

By Robert R. Remy<sup>1</sup>

## Abstract

Seventeen stratigraphic sections totalling 4,514.3 m were investigated and previous reports studied in order to clarify and illustrate the stratigraphy of most of the Eocene part of the fluvial and lacustrine Green River Formation in the south-central part of the Uinta basin of Utah. In the study area, the carbonate marker unit marks the base of the main body of the formation and consists of approximately 130 m of micrite, carbonate grainstone, dolostone, green mudstone, siltstone, and sandstone that accumulated in shallow water along the fluctuating southern shore of Lake Uinta.

The overlying delta facies is herein divided into two informal units: (1) a lower, 375-m-thick sequence named the Sunnyside delta interval and (2) an upper, 150-m-thick sequence named the transitional interval. In the Nine Mile Canyon area the Sunnyside delta interval consists of sandstone, red and green mudstone, and shallow-water limestone deposited in a large, fluvially dominated delta complex. The transitional interval is characterized by an upward increase from the base of the unit in the amount of open-lacustrine dolostone, kerogenous laminated dolostone (oil shale), and dark mudstone and a decrease in the amount of marginal-lacustrine green mudstone and shallow-water limestone. These lithologic changes record a major, but gradual, expansion of Lake Uinta.

Several transgressive limestone units in the Sunnyside delta interval and transitional interval serve as local stratigraphic markers. The top of the transitional interval is placed at the top of the S1 marker unit. The rocks of the Sunnyside delta interval and transitional interval in Nine Mile Canyon interfinger updip (southward) with lower deltaic to alluvial plain sandstone, mudstone, and minor limestone of the

interfingering Green River and Colton Formations that crop out along the upper Roan Cliffs near Sunnyside, Utah.

In the area of Nine Mile Canyon the informal upper member of the Green River Formation overlies the transitional interval and consists of approximately 300 m of dark mudstone, dolostone, and kerogenous laminated dolostone (oil shale) and minor sandstone and siltstone. The generally fine grained rocks of the upper member were deposited in a low-energy open-lacustrine setting in Lake Uinta. The Mahogany oil-shale bed, S2 marker unit, Horse Bench Sandstone Bed, and an unnamed tuff serve as local to regional stratigraphic markers. The presence of the Mahogany oil-shale bed near the top of the Roan Cliffs demonstrates that the top 0–25 m of the Roan Cliffs is stratigraphically equivalent to the lower part of the upper member in Nine Mile Canyon.

Analysis of published paleontological data and <sup>40</sup>Ar/<sup>39</sup>Ar, K/Ar, and zircon fission-track dates suggests ages of approximately 54.0 Ma, 47.5 Ma, and 43 Ma for the base of the carbonate marker unit, the top of the transitional interval, and the top of the upper member, respectively, in the study area.

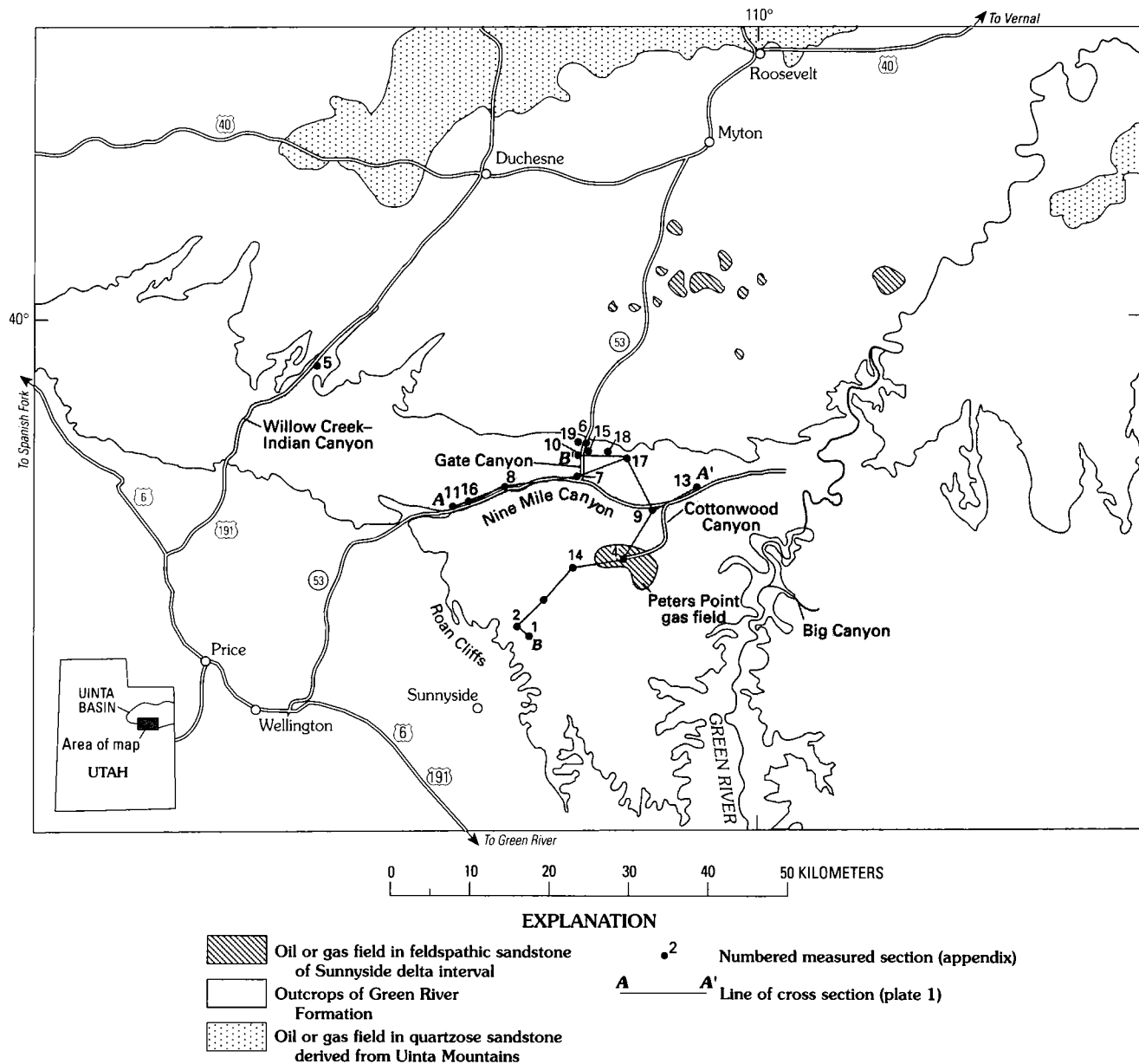
## INTRODUCTION

The Green River Formation in the Uinta basin of northeastern Utah (fig. 1) accumulated in and adjacent to a large lake basin (Lake Uinta) during Paleocene and Eocene time (fig. 2). According to the model proposed by Ryder and others (1976), the lower part of the formation can be divided into a central core of organic-rich open-lacustrine claystone and mud-supported carbonate surrounded by marginal-lacustrine facies consisting of claystone, sandstone, and carbonate rocks deposited in deltaic, interdeltic, and lake-margin carbonate-flat environments. The formation is enveloped by alluvial claystone, conglomerate, and sandstone of the Paleocene and Eocene Colton or Wasatch Formation and Eocene Uinta Formation that were deposited

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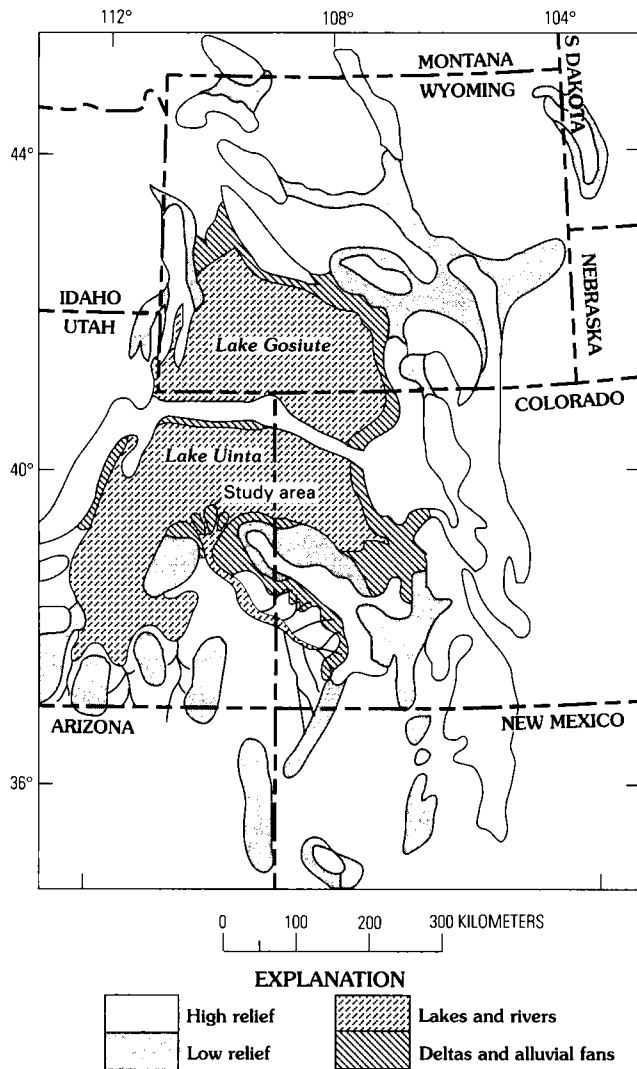
**Figure 1.** Outcrops of the Green River Formation in the south-central part of the Uinta basin. Geology modified from Hintze (1980). Positions of all oil and gas fields except Peters Point from Grugel and others (1983); position of Peters Point Field from Hendel (1957).

peripheral to the lake. Picard (1957, 1959), McDonald (1972), Fouch (1976, 1981), Ryder and others (1976), Fouch and Cashion (1979), Johnson (1985), Fouch and others (1987), and Bryant and others (1990) have illustrated and described the overall stratigraphy of the Green River Formation in the Uinta basin.

Numerous studies (Cashion, 1967; Picard and High, 1970; Fouch, 1975; Ryder and others, 1976; Pitman and others, 1982; Dickinson and others, 1986; Remy, 1991) demonstrate that one of the largest of several fluvial-deltaic complexes in the basin accumulated along the southern shore of Lake Uinta (fig. 2) and was centered around or east

of the Green River (fig. 1). This delta received feldspathic sand from basement rocks exposed in the Laramide-age San Luis uplift in southwestern Colorado (Dickinson and others, 1986). Marginal-lacustrine feldspathic sandstone in the Pariette Bench (Pitman and others, 1982), Duck Creek (Osmond, 1985), Pleasant Valley (Colburn and others, 1985), and Monument Butte and other (Oleson, 1986) oil and gas fields indicates that the delta extended into the center of the basin, where it interfingered with quartzose sediment derived from the Uinta Mountains to the north (Sanborn and Goodwin, 1965; Koesoemadinata, 1970; Castle, 1990) (fig. 1). The western edge of the delta was





**Figure 2.** Paleogeography of the central Rocky Mountain region during late early to middle Eocene time showing location of Lakes Gosiute and Uinta and study area. Modified from McDonald (1972).

west of the Willow Creek–Indian Canyon area (Ryder and others, 1976, figs. 15, 16) and the location of the eastern edge of the delta is poorly constrained.

In the Nine Mile Canyon area of the south-central part of the Uinta basin (fig. 1), the western margin of the delta that was centered around the Green River is well exposed. This part of the delta was informally named the Sunnyside delta by Remy (1989a) and consists of approximately 375 m of fluvial-deltaic sandstone and mudstone and carbonate (Remy, 1989a, b, 1991). Similar marginal-lacustrine rocks are reservoirs for many of the oil and gas fields in the basin subsurface (Fouch, 1975; Franczyk and others, 1989), and their updip equivalents are the host for the Sunnyside tar sand deposit on the Roan Cliffs. The fluvial-deltaic rocks are underlain by a 130-m-thick carbonate-rich sequence that

accumulated along the fluctuating southern shore of Lake Uinta before the major influx of sand deposited in the Sunnyside delta. The fluvial-deltaic deposits are overlain by about 500 m of generally fine grained, carbonate-rich, marginal- to open-lacustrine rocks that accumulated during a major expansion of the lake.

The stratigraphy and depositional environments of the Green River Formation in the south-central part of the Uinta basin were first described by Bradley (1931) (fig. 3, sections A and D). Subsequent workers (Dane, 1955; Ray and others, 1956; Hendel, 1957; Jacob, 1969; Ryder and others, 1976; Fouch and Cashion, 1979; Remy, 1989a, 1991; Weiss and others, 1990) provided additional information on the stratigraphy and depositional environments of the rocks and suggested a number of changes and additions to Bradley's (1931) stratigraphic nomenclature. Unfortunately, the variations in stratigraphic terminology used by different researchers and the occasionally vague descriptions of criteria used to identify boundaries between stratigraphic units make precise comparison of the results of these studies difficult. To date, no one has attempted a comprehensive review of this literature or conducted the detailed field work necessary to test the various stratigraphic schemes and produce a composite stratigraphic section for the Green River Formation in the south-central part of the Uinta basin. Moreover, little detailed information on the stratigraphy and lithology of the Green River Formation in the south-central part of the basin has been published, and the age of the rocks is poorly constrained, particularly in the lower part of the formation.

The purpose of this report is to provide a detailed analysis of the stratigraphy of most of the Eocene part of the Green River Formation in the area of Nine Mile Canyon and the Roan Cliffs near the Sunnyside tar sand deposit (fig. 1). Specifically, the report (1) summarizes and evaluates studies of the surface stratigraphy of most of the Eocene part of the Green River Formation in the south-central part of the Uinta basin, (2) describes and illustrates the stratigraphy of the rocks and briefly describes their lithology, depositional environments, and age, (3) illustrates the stratigraphic relation between the rocks exposed in Nine Mile Canyon and those exposed updip in the upper Roan Cliffs, and (4) presents 15 detailed measured sections and 2 cross sections of the formation.

Acknowledgment is made to the Donors of The Petroleum Research Fund, administered by the American Chemical Society, for support of this research. I would also like to thank Dag Nummedal, J.E. Hazel, C.L. McCabe, and R.E. Ferrell (Louisiana State University), W.B. Cashion and T.D. Fouch (U.S. Geological Survey), and J.A. Campbell (Oklahoma Geological Survey) for their valuable comments and suggestions; J.H. Hutchison (University of California, Berkeley) for identifying some turtle fragments;

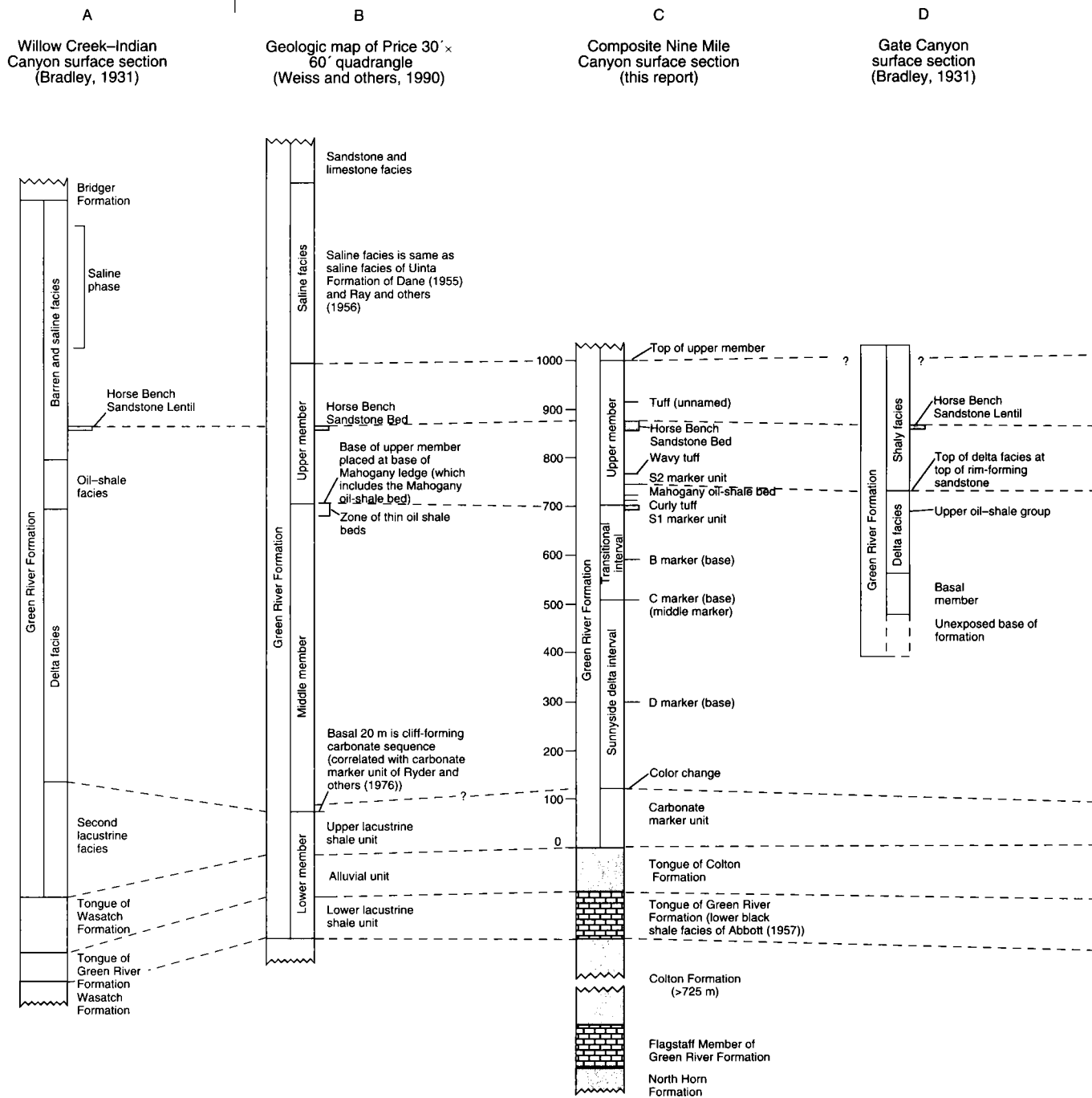


Figure 3 (above and facing page). Stratigraphic nomenclature of the Green River Formation in the south-central part of the Uinta basin, Utah.

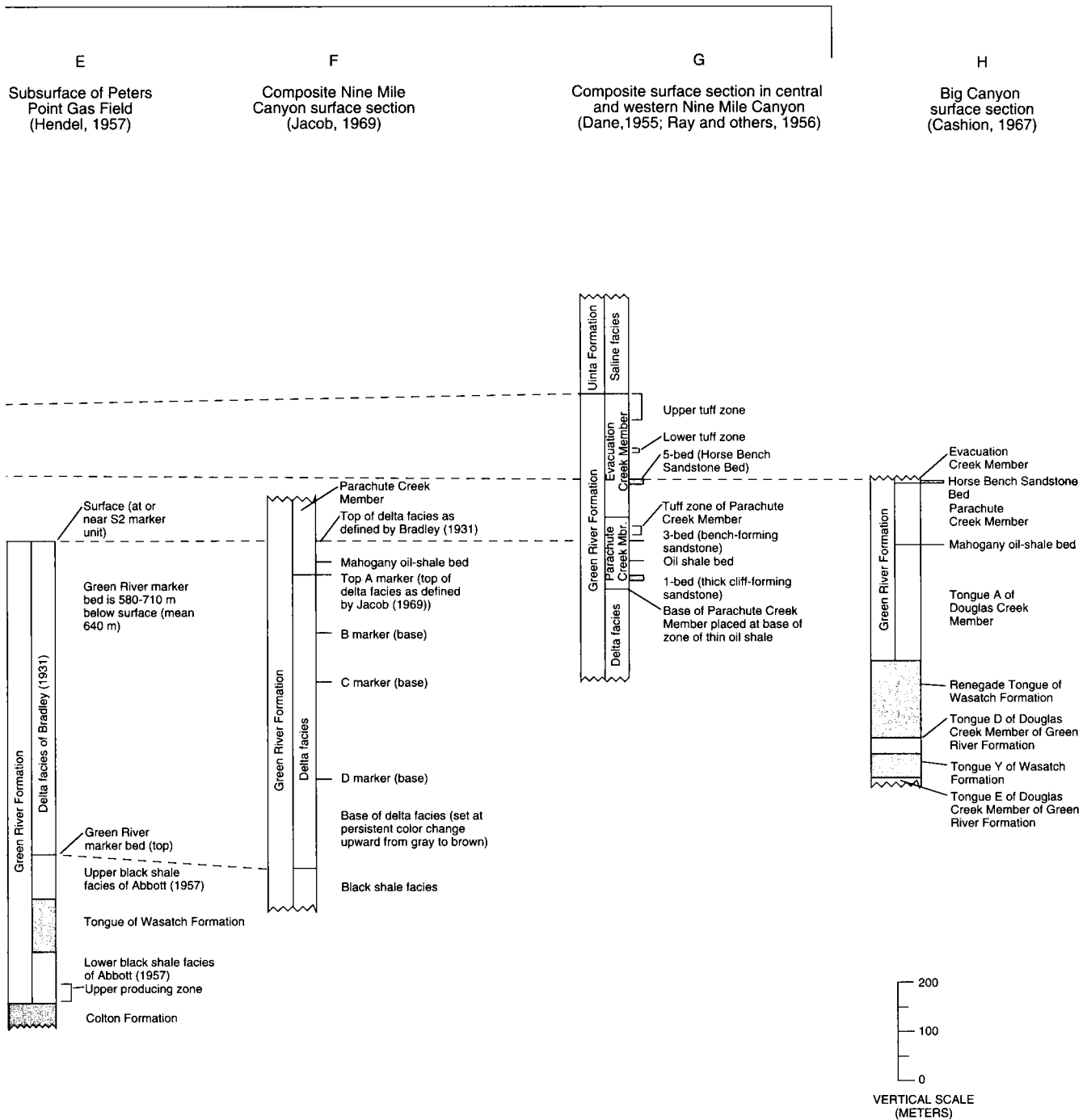
Xudong Ying, Sean McLaughlin, and Richard Denne (Louisiana State University) for aiding me in the field; and Xudong Ying for providing me with measured sections 17, 18, and 19 of this report.

**STUDY AREA AND METHODS**

The study area in the south-central part of the Uinta basin (fig. 1) is bounded on the north by Nine Mile Canyon

NINE MILE CANYON

NEAR GREEN RIVER



and the lower 5 km of Gate Canyon, on the south by the Roan Cliffs near Sunnyside, Utah, on the west by the junction of Minnie Maude Creek and Nine Mile Creek, and on the east by the junction of Nine Mile Canyon and North Franks Canyon. The stratigraphic interval examined in this report includes all but the basal 30 m of the Eocene carbonate marker unit of Ryder and others (1976, p. 497),

the delta facies of Bradley (1931), and the upper member of Weiss and others (1990) (equivalent to a part of the Parachute Creek Member of the Green River Formation of Cashion and Donnell (1974)).

Seventeen stratigraphic sections (fig. 1, appendix) totalling 4,514.3 m were investigated in order to determine the lithology, color, bedding thickness, grain size, nature of

bounding surfaces, sedimentary structures, geometry, and fossil content of the rocks and to determine the position of stratigraphic markers. Fifteen of the seventeen measured sections that form the basis of this study are shown. In order to facilitate description of the measured sections, 12 lithofacies were defined. Their primary lithologic and sedimentologic characteristics and interpreted depositional environments are summarized in table 1, and their geographic and stratigraphic distributions are shown in table 2. The lithofacies are grouped into five depositional assemblages, which are described and illustrated on plate 1.

Photomosaics of the walls of Nine Mile Canyon and its tributaries and the Roan Cliffs were used to analyze the geometry of the rocks and to trace stratigraphic markers. Limestones, tuffs, distinctive sandstone units, and other types of lithologic markers were used to correlate the sections (appendix). The stratigraphic positions of the stratigraphic markers employed in this study are listed in the appendix, and correlations of the measured sections are shown on plate 1.

## LITHOSTRATIGRAPHY OF THE GREEN RIVER FORMATION: NINE MILE CANYON

### Units Underlying the Main Body of the Green River Formation

The Green River Formation can be visualized as a jagged-edged lens of open-and marginal-lacustrine rocks enveloped by alluvial rocks of the Paleocene and Eocene Colton or Wasatch Formation and the Eocene Uinta Formation (Cashion, 1967, p. 8). West of the Green River the Colton Formation is separated from the underlying similar-appearing North Horn Formation by the Flagstaff Member of the Green River Formation (as defined by Fouch, 1976) (Weiss and others, 1990). In areas where the Flagstaff Member is absent or thin, as it is east of the Green River, it has been common practice to group all of the rocks between the top of the Cretaceous and the base of the Green River Formation with the Wasatch Formation (McDonald, 1972, p. 249; Weiss and others, 1990).

In the area of Nine Mile Canyon, the Flagstaff Member is approximately 91 m thick and is overlain by more than 725 m of mainly alluvial rocks of the Colton Formation (Fouch and others, 1976, p. 365) (fig. 3, section C). The Colton Formation thins northward toward the center of the basin where the thickened Flagstaff Member and the main body of the Green River Formation merge and form a continuous lacustrine sequence (Fouch, 1976; Ryder and others, 1976)

The interfingering contact between the Wasatch Formation of Bradley (1931) and the overlying Green River Formation in the south-central part of the Uinta basin was

first described by Bradley (1931). In the Willow Creek–Indian Canyon area (fig. 1) Bradley divided the rocks beneath his delta facies into (from base to top) (1) a tongue or phase of the Green River Formation, consisting of about 60 m of paper shale, marlstone, limestone, and minor carbonaceous shale and coal, (2) a tongue of the Wasatch Formation, consisting of 115 m of sandstone and drab, buff, greenish, and red mudstone, and (3) a second lacustrine phase or facies of the Green River Formation, consisting of 230 m of light-gray and brown shale, limestone, and minor sandstone (fig. 3, section A). In Gate Canyon (fig. 1), Bradley (1931) identified what he believed to be the basal member of the Green River Formation that he correlated with basal units in the Willow Creek–Indian Canyon area (fig. 3, section D). Results of my investigation indicate, however, that the base of the surface section at Gate Canyon is several hundred meters stratigraphically above the top of the second lacustrine phase in the Willow Creek–Indian Canyon area.

Picard (1955, p. 83) designated the term “black shale facies” for dark-gray to black shale, limestone, grayish-green shale, sandstone, and minor oil shale that he placed at the base of the Green River Formation in the basin subsurface. He correlated the black shale facies with Bradley’s (1931) tongue of the Green River Formation and the tongue of the Wasatch Formation. Abbott (1957) extended the black shale facies to surface exposures and recommended that the terms “upper black shale facies,” “Colton tongue,” and “lower black shale facies” be substituted for Bradley’s (1931) second lacustrine facies, tongue of the Wasatch, and basal tongue of the Green River Formation, respectively. Picard and others (1973) divided the black shale facies into four lacustrine units designated “A” through “D” and one fluvial unit designated the “Wasatch tongue” of the black shale facies.

Recently, Weiss and others (1990) mapped the lower units of the Green River Formation as the lower member (fig. 3, section B). They observed that the lower member of the Green River Formation is composed of three lithologic units (base to top): (1) a lower lacustrine shale unit, which they correlated with the basal tongue of the Green River Formation of Bradley (1931), (2) an alluvial unit, which they correlated with Bradley’s tongue of the Wasatch Formation, and (3) an upper lacustrine shale unit, which they correlated with Bradley’s second lacustrine facies (fig. 3, compare sections A and B).

The interfingering Colton–Green River contact is well exposed in western Nine Mile Canyon. Fouch and others (1976, p. 365) described an “unnamed tongue of the Green River Formation” as a 96-m-thick interval of ostracode grainstone, thin mud-supported organic-rich carbonate rocks, grayish-green claystone, and sandstone. The thickness and lithology of this unit and its stratigraphic position above the main body of the Colton Formation suggest that it is equivalent to Bradley’s (1931) basal tongue

**Table 1.** Summary of major lithologic and sedimentologic characteristics and interpretation of lithofacies of the Eocene part of the Green River Formation in the south-central part of the Uinta basin, Utah

Lithofacies definition	Code	Lithology and grain size	Sedimentary structures	Geometry and thickness	Other characteristics	Associated lithofacies	Interpretation
Thick (>15 m), scour-enclosed sandstone	Sa	Siltstone and sandstone (62-280 $\mu$ , mean=150 $\mu$ ), some coarsen or fine upward, most have multiple vertical grain-size trends	Trough crossbeds, current and less common climbing ripples, planar laminations, much structureless, no consistent vertical arrangement of structures	Thinner sandbodies lenticular to tabular; thicker sandbodies tabular; 57 percent of sandbodies amalgamated, 15-41 m thick (mean=23.2 m)	Bases sharp and flat to scoured, basal intraformational conglomerate abundant, scours and intraformational conglomerate within sandbodies abundant	Common: Mr, Mg, Se, Sf Less common: Sb, L, C Rare: Ia Never: Sc, Sd, Ib	Nonsinuuous streams on upper delta to alluvial plain
Laterally discontinuous sandstone, 3-15 m thick	Sb	Siltstone and sandstone (62-300 $\mu$ , mean=125 $\mu$ ), 30 percent fine upward, 7 percent coarsen upward, 43 percent have multiple trends, 20 percent have uniform grain size	Trough crossbeds, current and wave ripples, planar laminations, much structureless, many sandbodies have upward decrease in size of structures	Lenticular to tabular geometry, sloping channel edges common; about 25 percent stacked sandbodies, mean thickness=5.8 m	Bases sharp and flat to scoured, lateral-accretion bedding and basal intraformational conglomerate abundant, scours and intraformational conglomerate within sandbodies common	Common: Mr, Mg, Se, Sf, L Less common: Sa, Sc, C, Rare: Ia, Ib (?) Never: Sd	Meandering delta distributary channels on delta plain and stacked crevasse splays and overbank sandsheets
Thick (>15 m), laterally interfingering sandstone	Sc	Siltstone and sandstone (62-275 $\mu$ , most less than 150 $\mu$ ), uniform grain size or multiple fining- and coarsening-upward cycles	Current and wave ripples, planar and wavy planar laminations, hummocky cross-stratification (?), rare trough crossbeds and convolute bedding, wave-generated structures more common in lower halves of sandbodies	Lenticular geometry with irregular edges that inter-finger laterally with other rocks, thick sandbodies composed of amalgamated lenticular sandbodies, amalgamated sandbodies 15-40+ m thick	Bases generally sharp and flat, basal intraformational conglomerate rare, internal scours and intraformational conglomerate common, rare downstream accretion bedding	Common: Mr, Mg, Se, Sf, L, Sb Rare: C Never: Sa, Sd, Ia, Ib	Stacked and amalgamated lenticular delta mouth bars
Laterally continuous sandstone, 3-15 m thick	Sd	Sandstone (62-350 $\mu$ ), most have multiple fining- and coarsening-upward cycles, some fine upward, some contain green and gray mudstone	Trough crossbeds and planar laminations common, locally common ripples, convolute bedding and structureless zones, no consistent vertical arrangement of structures	Tabular geometry (can be traced for at least 2 km), consists of stacked sandbodies, 4.5-11.5 m thick	Base always sharp, basal scour with intraformational conglomerate common	Common: Se, Mg, Ia, Ib Never: all other lithofacies	Delta (front?) deposits that accumulated in Lake Uinta during a regional regression
Thin (<3 m) sandstone without basal or internal scour, coarsening-upward grain size, or accretion bedding	Se	Siltstone and fine-grained sandstone (generally less than 125 $\mu$ ), most have uniform grain size, few fine upward	Current ripples, planar laminations, small-scale trough crossbeds, and mudcracks common, locally abundant wave ripples and wavy planar laminations	Tabular geometry (lateral continuity commonly more than a few hundred meters), lithofacies 0.5-3.0 m thick, individual beds a few centimeters to 3.0 m thick (but most less than 1.5 m thick)	Individual beds commonly have sharp and flat bases and tops, lithofacies generally encased in mudstone	Common: Sa, Sb, Sc, Sd, Sf, Mg, Mr, L, Ia, C Rare: Ib	Fluvial overbank and deltaic sandsheets that accumulated in fluvial, lower delta plain, and shallow lacustrine settings

**Table 1.** Summary of major lithologic and sedimentologic characteristics and interpretation of lithofacies of the Eocene part of the Green River Formation in the south-central part of the Uinta basin, Utah—Continued

Lithofacies definition	Code	Lithology and grain size	Sedimentary structures	Geometry and thickness	Other characteristics	Associated lithofacies	Interpretation
Thin (<3 m) sandstone with basal or internal scour, coarsening-upward grain size, or accretion bedding	Sf	Siltstone and fine-grained sandstone (generally less than 175 $\mu$ ), most have uniform grain size, some fine or coarsen upward	Same as lithofacies Se except trough crossbeds more common	Tabular to lenticular geometry, lithofacies 0.5-3.0 m thick, individual beds as thick as 3.0 m	Basal scour and amalgamation of sandstone beds common, downstream accretion locally abundant, lithofacies generally encased in mudstones	Common: Sa, Sb, Sc, Sd, Se, Mg, Mr, L, Ia, C Rare: Ib	Crevasse splays, crevasse splay channels, and small, delta distributary channels that accumulated in fluvial, lower delta plain, and shallow lacustrine settings
Sand- and(or) mud-filled channel	C	Red and green mudstone, siltstone, and fine-grained sandstone (generally less than 150 $\mu$ )	Mudstone generally structureless; sandstone and siltstone contain ripples and planar laminations and are commonly structureless	Mudstone-, sandstone-, and siltstone-filled channels, size of channels from few meters wide to about 100 m wide by 10 m deep	Scours generally cut interbedded sandstone and mudstone, basal intraformational conglomerate common	Common: Mg, Mr, Se, Sf, L, Sa, Sb, Sc (?) Never: Ia, Ib, Sd	Passively filled abandoned channels (most probably are crevasse channels)
Green mudstone	Mg	Green, greenish-gray, and light-gray mudstone, minor sandstone, siltstone, limestone, and red and purple mudstone	Most mudstone structureless, rare planar laminations, ripples, small burrows, rootlets (?), mudcracks, and syneresis cracks	Tabular geometry, lithofacies 0.5-25 m thick, individual beds a few centimeters to 5 m thick	Base and top of individual beds sharp to gradational, ostracodes common in mudstone	Common: all lithofacies except Ib Rare: Ib	Shallow water subaqueous mudflats in interdistributary bays, in shallow nearshore parts of the lake, and perhaps in delta plain ponds and lakes
Red mudstone	Mr	Red and purple mudstone, minor sandstone, siltstone, limestone, and green, greenish-gray, and light-gray mudstone	Same as lithofacies Mg	Same as lithofacies Mg	Base and top of individual beds sharp to gradational, ostracodes rare	Common: all lithofacies except L, Ia, Ib Rare: L Never: Ia, Ib	Intermittently subaerially exposed mudflats
Limestone	L	Ostracode, ooid, intraclast, and pellet grainstone, micrite, and stromatolite, minor thin beds of sandstone, siltstone, green mudstone, and dolostone (including oil shale)	Ripples, small-scale trough crossbeds, planar and wavy planar laminations, and hummocky cross-stratification (?) in grainstones; some micrite has planar laminations but most is structureless; stromatolite has algal laminations	Tabular geometry for both lithofacies and individual beds, lithofacies 0.5-25 m thick, individual beds a few centimeters to a few meters thick	Bases of beds generally flat and unscoured, complex interbedding and interlaminations of different limestone types common	Common: all lithofacies except Mr, Ia, Ib Rare: Mr, Ib, Ib	Limestones deposited in shallow, quiet to wave-agitated water in interdistributary bays, in nearshore regions of the lake, and perhaps in delta plain ponds and lakes

**Table 1.** Summary of major lithologic and sedimentologic characteristics and interpretation of lithofacies of the Eocene part of the Green River Formation in the south-central part of the Uinta basin, Utah—Continued

Lithofacies definition	Lithology and grain size	Sedimentary structures	Geometry and thickness	Other characteristics	Associated lithofacies	Interpretation
Brown and gray mudstone, dolostone (<30 percent), and minor sandstone and siltstone	Gray to brown mudstone and dolostone (including oil shale), minor green mudstone, limestone, sandstone, and siltstone	Much dolostone and mudstone structureless, some has planar laminations in places; sandstones have a variety of structures including ripples, planar and wavy planar laminations, hummocky cross-stratification, and trough crossbeds	Tabular geometry for both lithofacies and individual beds, lithofacies 0.5 to more than 100 m thick, individual beds as thick as 10 m	Some coarsening- and fining-upward trends, individual beds commonly have sharp flat bases and tops and are laterally continuous, ostracodes abundant in places	Common: lb, Mg, Se, Sd, Sf Less common: Sb, L Rare: Sa, C, Sc Never: Mr	Proximal open-lacustrine environment; carbonate and siliciclastic mud deposited in low-energy nearshore to offshore regions of lake, some storm transport of sand into lake
Brown and gray mudstone, dolostone (>30 percent), and minor sandstone and siltstone	Similar to lithofacies la except more dolostone and less gray to brown mudstone, siltstone, sandstone, and green mudstone	Same as lithofacies la	Same as lithofacies la	Same as lithofacies la	Common: la, Sd Less common: Mg, Se, Sf, L Rare: Sa, Sb, Sc, Never: Mr, C	Distal open-lacustrine environment; same as lithofacies la except generally deeper water (?) and lower energy

of the Green River Formation and Abbott's (1957) lower black shale facies. Little (1988) described the depositional environments, petrology, and diagenesis of limestone in this unit.

In western Nine Mile Canyon the stratigraphic interval equivalent to the lower black shale facies of Abbott (1957) is overlain by a red claystone, siltstone, and lenticular sandstone assemblage (Fouch and others, 1976, p. 365). These rocks, which were described as "an unnamed tongue of the Colton" by Fouch and others (1976), are presumably stratigraphically equivalent to Bradley's (1931) tongue of the Wasatch and Abbott's (1957) Colton tongue.

In a study of the subsurface stratigraphy and lithology of the lower part of the Green River Formation in the Peters Point gas field (fig. 1), Hendel (1957) identified and briefly described the lower black shale, the Wasatch tongue, and the upper black shale (fig. 3, section E). He placed the Colton-lower black shale contact at the base of the lowest typical lake bed. His lower black shale consists of approximately 110 m of calcareous greenish-gray mudstone and shale, red mudstone, limestone, and sandstone. The lenticular sandstone in the lower part of this interval is the main producing interval for the Peters Point field. The overlying Wasatch tongue of Hendel (1957) is approximately 110 m thick and consists of fluvial deposits and minor lacustrine units. The stratigraphic positions and compositions of these units strongly suggest that the lower black shale is equivalent to Bradley's (1931) tongue of the Green River Formation and Abbott's (1957) lower black shale facies and that the Wasatch tongue is equivalent to Bradley's (1931) tongue of the Wasatch and Abbott's (1957) Colton tongue. The upper black shale is equivalent to the carbonate marker unit of this report and to Bradley's (1931) second lacustrine facies (fig. 3).

## Carbonate Marker Unit

The carbonate marker unit of Ryder and others (1976) marks the base of the main body of the Green River Formation in the area of Nine Mile Canyon. In eastern Nine Mile Canyon the unit is approximately 130 m thick, the basal 25–30 m of which is poorly exposed. The upper 105 m of the unit is well exposed and consists of ostracode and ooid grainstone and micrite of the L lithofacies (16.3 percent), green mudstone of the Mg lithofacies (14.2 percent), sandstone of the Sb (12.5 percent), Se (9.9 percent), and Sf (5.7 percent) lithofacies, dark laminated mudstone and kerogenous laminated dolostone (oil shale) of the Ia (25.3 percent) and Ib (5.4 percent) lithofacies, and covered intervals (10.7 percent) probably underlain by mudstone or dolostone (table 2; appendix, units 1–66 of measured section 11). These rocks accumulated along the fluctuating southern shore of Lake Uinta (Fouch and others, 1976; Remy, 1989a, b, 1991) in lake-margin carbonate-flat, subaqueous mudflat, crevasse-splay, overbank and shallow-

**Table 2.** Stratigraphic and geographic distribution of lithofacies of the Eocene part of the Green River Formation in the south-central part of the Uinta basin, Utah

[In percent. Leader (–) indicates not present. Lithofacies defined in table 1]

Lithofacies	Nine Mile Canyon and tributaries <sup>1</sup>					Roan Cliffs <sup>2</sup>	
	Carbonate marker unit	Sunnyside delta interval	Transitional interval <sup>3</sup>		Upper member	Interfingering Green River and Colton Formations	Upper member of Green River Formation
			Lower	Upper			
Sa.....	–	–	–	–	–	37.7	–
Sb.....	12.5	23.6	9.5	12.1	4.6	14.8	–
Sc.....	–	4.0	–	–	–	–	–
Sd.....	–	–	–	5.2	5.0	–	–
Se.....	9.9	12.8	12.4	8.9	3.8	8.8	4.4
Sf.....	5.7	2.8	2.3	0.8	1.5	0.4	–
C.....	–	–	–	–	–	–	–
Mr.....	–	7.8	0.4	–	–	9.7	–
Mg.....	14.2	19.0	33.2	23.6	2.8	9.7	24.3
L.....	16.3	6.2	13.7	5.5	0.2	2.9	15.7
Ia.....	25.3	0.5	0.6	6.4	39.1	0.6	7.8
Ib.....	5.4	–	–	3.4	12.2	–	47.8
Covered interval	10.7	23.3	27.9	34.1	30.8	15.4	–

<sup>1</sup>Includes measured sections 4, 6–11, 13–17 (appendix).

<sup>2</sup>Includes measured sections 1 and 2 (appendix).

<sup>3</sup>Boundary between upper and lower parts of transitional interval placed at the B marker.

lacustrine sandsheet, delta distributary channel, and proximal open-lacustrine environments.

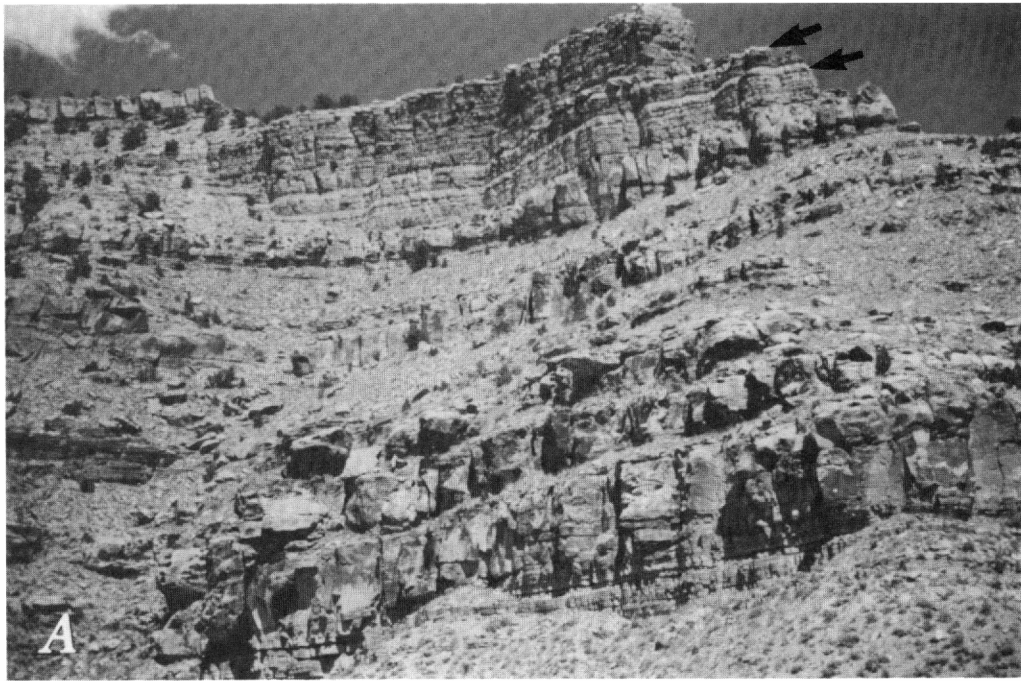
In the subsurface, the top of the carbonate marker unit is placed at the carbonate marker, a well-log response that can be recognized in most of the subsurface part of the basin (Ryder and others, 1976). In his study of the subsurface stratigraphy and lithology of the lower part of the Green River Formation in the Peters Point gas field, Hendel (1957) placed the boundary between the delta facies of Bradley (1931) and the upper black shale facies of Abbott (1957) at the Green River marker bed, which he described as a “persistent limestone” (fig. 3, section E). His upper black shale facies is a 90-m-thick interval of limestone, black and gray shale, and sandstone (Hendel, 1957, fig. 3). Similarities in stratigraphic position, lithology, and thickness suggest that the upper black shale facies is stratigraphically equivalent to the carbonate marker unit and that the Green River marker bed of Hendel (1957) is equivalent to the carbonate marker of Ryder and others (1976) (fig. 3, sections C and E).

I placed the top of the carbonate marker unit at a sharp distinctive change in the weathered color of the rocks (fig. 3, section C). The carbonate-rich carbonate marker unit weathers light gray, whereas the overlying carbonate-poor Sunnyside delta interval weathers light brown. Jacob (1969) used the same criteria to place the boundary between the black shale facies (carbonate marker unit of this report) and the delta facies of Bradley (1931) (fig. 3, section F).

## Delta Facies (Sunnyside delta interval and transitional interval)

The interval between the carbonate marker unit and the mudstone- and dolostone-rich upper member consists of approximately 550 m of mainly fluvial and shallow-lacustrine sandstone and mudstone and shallow-water limestone; some dolostone and dark mudstone is present near the top of the sequence. Bradley (1931) examined this interval near the Duchesne–Uintah County line, approximately 9 km east of my easternmost measured section (measured section 13) (fig. 1), and at Gate Canyon. Because of the similarity of the sections, only the Gate Canyon section is shown in figure 3 (section D). Bradley (1931) divided the interval below his shaly facies (upper member of this report) into (1) the basal member, consisting of approximately 76 m of greenish-gray shale and subordinate sandstone, limestone, and low-grade oil shale, and (2) the delta facies, consisting of 152–183 m of sandstone (which constitutes 75–80 percent of the interval) and greenish-gray mudstone (fig. 3, section D). However, because the basal 80 m of the surface section at Gate Canyon is not significantly different from overlying rocks (fig. 4A; appendix, measured section 7), subsequent researchers (Hendel, 1957; Jacob, 1969; Remy, 1989a) dropped the term “basal member” and referred to all of the rocks beneath Bradley’s (1931) shaly facies as the “delta facies of Bradley (1931).” According to McDonald (1972), the delta facies is equivalent to the





**Figure 4** (above and following pages). Photographs of the Green River Formation. *A*, Sunnyside delta and transitional intervals at the junction of Gate and Nine Mile Canyons. Thick sandstones of Sb lithofacies (table 1) and associated thin sandstones of Se and Sf lithofacies, red and green mudstones of Mr and Mg lithofacies (covered intervals), and limestone of L lithofacies were deposited in and adjacent to a large, fluviially dominated delta. At this location the C marker of this report is approximately 15 m above a pair of prominent yellow-weathering limestones (arrows), the C2 and C3 markers of Jacob (1969). The C marker separates the Sunnyside delta interval from the overlying transitional interval. The interval from the base of the photograph to the C marker is approximately 170 m thick. *B*, Uppermost transitional interval and overlying open-lacustrine upper member in Gate Canyon. Note the S1 marker unit (S1), S2 marker unit (S2), and Horse Bench Sandstone Bed (HB). See measured section 10 (appendix) for a description of the rocks between the S1 and S2 marker units at this location. The interval from the base of the S1 unit to the top of the S2 unit is approximately 60 m thick. *C*, Stratigraphy of the upper part of the Green River Formation in central Nine Mile Canyon. Note the upper Sunnyside delta interval (SD) and transitional interval (T) exposed in the inner gorge of Nine Mile Canyon, the S2 marker unit (S2) underlying a broad plateau, the Horse Bench Sandstone Bed (HB) underlying an upper plateau, and the top of the upper member (arrows). View is from small airplane at approximate position of measured section 9 (fig. 1), looking eastward toward the Green River (not visible). Photograph provided by Xudong Ying (Louisiana State University). *D*, Stratigraphy of the upper part of the Green River Formation in eastern Nine Mile Canyon. Note the transitional interval (T), S2 marker unit (S2), and the broad plateau held up by Horse Bench Sandstone Bed (HB). View is from small airplane approximately half way between measured section 13 (fig. 1) and the Green River (not visible). Photograph provided by Xudong Ying (Louisiana State University). *E*, Bed of ooids with ostracode nuclei in D marker. Penny for scale.

Douglas Creek Member of the Green River Formation in the eastern part of the Uinta basin (fig. 3, section H).

Picard (1957) recommended that the term “green shale facies” be substituted for the term “delta facies” in the western part of the basin in order to avoid environmental interpretation in a stratigraphic term and because the term is more indicative of the sediment type. The middle member of the Green River Formation of Weiss and others (1990) is equivalent to most of the delta facies of Bradley (1931).

Bradley (1931, p. 15) stated that “in Gate Canyon, the writer estimates that about 300 feet at the base is not exposed.” It is unclear whether Bradley was referring to the

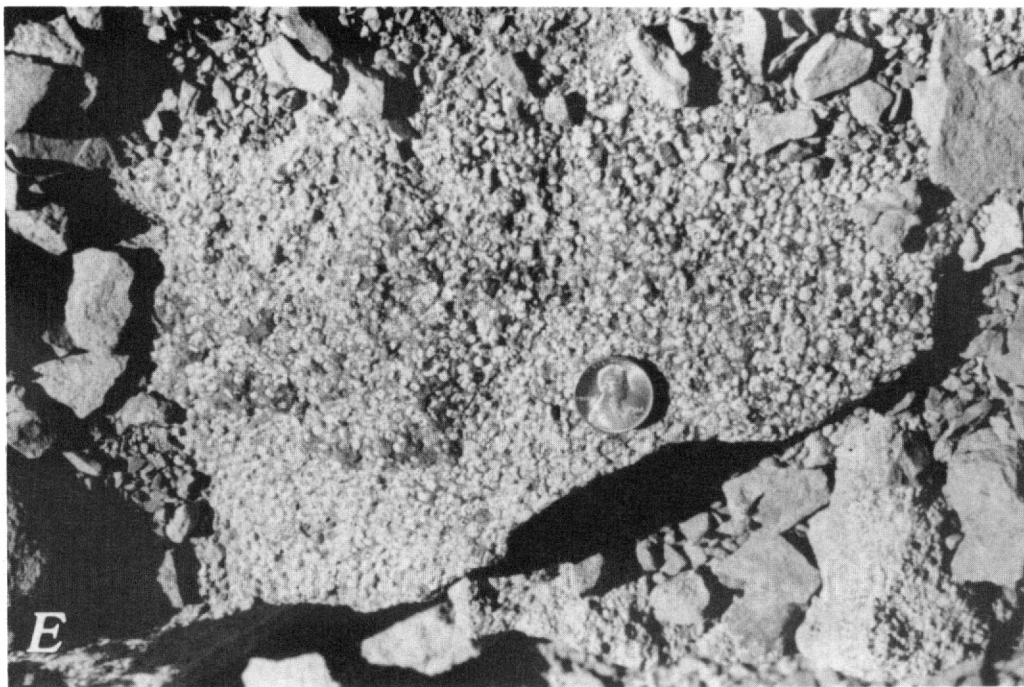
base of the main body of the Green River Formation (that is, the base of the delta facies) or to the contact between his tongue of the Green River Formation and the underlying main body of the Colton Formation. Detailed correlations of the rocks (plate 1) indicate that Bradley was incorrect in either case. The base of the delta facies, as defined to include Bradley’s (1931) basal member, is actually 160 m below the floor of Gate Canyon (see measured section 7, plate 1), and the contact between the tongue of the Green River Formation and the underlying main body of the Colton Formation is about 500 m below the floor of the canyon. Moreover, Bradley (1931, plate 3) erroneously



correlated his basal member at Gate Canyon with his basal lacustrine tongue, tongue of the Wasatch Formation, and second lacustrine phase in the Willow Creek–Indian Canyon area. His miscorrelation, together with the fact that he underestimated the thickness of the basal member and delta facies by approximately 100 m, led to his erroneous conclusion that the delta facies thickens dramatically westward toward the Willow Creek–Indian Canyon area. Results of my study indicate that the delta facies (Sunnyside

delta interval and transitional interval of this report) is about the same thickness (550 m) in the Nine Mile Canyon and Willow Creek–Indian Canyon areas (fig. 3, compare sections A and C).

Several approaches have been taken in defining the top of the delta facies. Bradley (1931, p. 16, plate 9B) noted that the top of the delta facies is near the top of the inner gorge of eastern Nine Mile Canyon (which he referred to as the “canyon of Minnie Maude Creek”). In central and



eastern Nine Mile Canyon, the inner gorge of the canyon and its tributaries are held up by two sandstone-rich intervals (fig. 4B). The lower sandy interval was mapped as the “1-bed” by Ray and others (1956) and informally named the “S1 marker” by Fouch and others (1976, p. 369). The upper sandy interval was mapped as the “3-bed” by Ray and others (1956) and informally named the “S2 marker unit” by Fouch and others (1976). Both units form narrow to broad plateaus in most places and are distinguished on the basis of

their relationship with the Mahogany oil-shale bed (see below), which is between the S1 and the S2 units (plate 1). The S1 and S2 units are separated by 35–60 m of slope-forming, generally poorly exposed dolostone and mudstone and minor sandstone and siltstone.

The S1 and S2 marker units exhibit variable lithology. In and near Gate Canyon for example, measured sections 7, 10, and 17 in the appendix) the S1 marker unit is a thick (6.7–11.5 m), prominent, cliff-forming, trough

cross-stratified sandstone, and the S2 marker unit consists of about 1 m of very fine grained, hummocky cross-stratified sandstone and, in places, mudstone (see, for example, unit 25 of measured section 10 in the appendix)(fig. 4B). Both units underlie plateaus in this region. Toward the east, however, both marker units change lithology. The S1 thins, is finer grained, and is much less prominent than in Gate Canyon. The S2, on the other hand, thickens, is much coarser grained, and, in places, resembles the S1 of Gate Canyon. In this region the S2 underlies a broad plateau that can be traced continuously from a position several kilometers east of Gate Canyon to the Green River (figs. 4C, D).

Bradley (1931) did not directly specify which of the two rim-forming sandstones at the top of the inner gorge of Nine Mile Canyon defines the top of his delta facies nor did he publish his measured sections in Nine Mile Canyon. He did state, however, that a set of oil shales below the top of his delta facies represents the upper oil-shale group of the Parachute Creek Member (although he did not apply the term "Parachute Creek Member" to any beds west of the Green River). The Mahogany oil-shale bed is within the upper oil-shale group (W.B. Cashion, U.S. Geological Survey, written commun., 1990) and in Gate Canyon is between the S1 and the S2 marker units (Fouch and others, 1976). Therefore, the S1 marker unit must be below the top of the delta facies; thus Bradley (1931) placed the contact between his delta facies and his overlying shaly facies at or near the S2 marker unit.

Dane (1954, 1955) and Ray and others (1956), on the other hand, placed the top of the delta facies at the base of a set of oil shales that is about 30 m below their 1-bed (S1 marker unit of this report) (fig. 3, section G). These oil shales are present in several measured sections of this report (appendix), including section 9.

Jacob (1969) placed the top of the delta facies at the top of a persistent sandstone that is below the main body of oil shale (fig 3, section F). In his Devils Canyon measured section this sandstone, which he called "marker A," is approximately 55 m below the top of the rim-forming sandstone picked by Bradley (1931) as the top of the delta facies and 25 m below the Mahogany oil-shale bed. The lithology and stratigraphic position of marker A relative to the Mahogany oil-shale bed and the S2 marker unit (see measured section 10 in the appendix) indicate that marker A is equivalent to the 1-bed of Ray and others (1956) and the S1 marker unit of Fouch and others (1976).

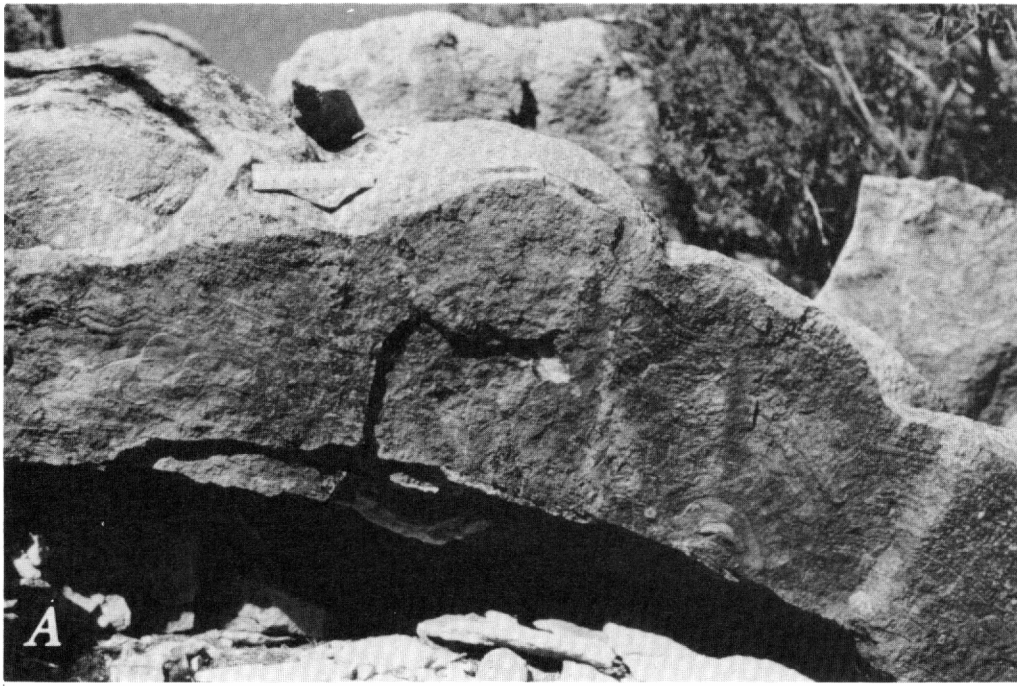
Weiss and others (1990) placed the top of their middle member of the Green River Formation (delta facies of Bradley, 1931) at the base of the Mahogany ledge, a zone of several oil shale beds that includes the Mahogany oil-shale bed. The Mahogany ledge directly overlies the S1 marker unit. For ease of mapping, however, they drew the boundary between the upper and middle members at the top

of the Mahogany oil-shale bed, which is about 10 m above the base of the Mahogany ledge (fig. 3, section B).

Several laterally continuous, yellow-weathering limestone units were employed by Jacob (1969) and by me to correlate and subdivide Bradley's (1931) delta facies (Sunnyside delta interval and transitional interval of this report). The stratigraphic positions of these markers are shown in the appendix and their correlations are illustrated on plate 1. Jacob's (1969) D marker consists of approximately 2.0 m of carbonate mudstone, ostracode grainstone, domal stromatolite, greenish-gray mudstone, and a distinctive bed of oolite grainstone containing ostracode nuclei (fig. 4E; appendix, units 3 and 4 of measured section 8). This unit is equivalent to Remy's (1989a) ostracode oolite marker; however, in this report I used Jacob's original name for the marker because it has precedence over the name I employed in 1989 and because the marker does not everywhere contain oolites with ostracode nuclei. The D marker is approximately 160 m above the top of the carbonate marker unit (plate 1) and can be traced from a position several kilometers west of measured section 16 through measured section 8 to a position 3 km west of measured section 7 (fig. 1) where it goes into the subsurface.

Jacob's (1969) C marker consists of three ostracode grainstones that he designated (from base to top) "C3," "C2," and "C1." Markers C3 and C2 form a prominent yellow double band that can be traced visually in the upper walls of central and eastern Nine Mile Canyon (fig. 4A). Jacob's (1969) C1 marker is approximately 4–17 m above the C2 marker and consists of 2–8 m of ostracode grainstone, domal stromatolites as much as 1 m wide by 50 cm high (fig. 5A), micrite, and minor sandstone and mudstone (see, for example, units 100 and 101 of measured section 8 and units 83–85 of measured section 9 in the appendix). Both the thickness of the marker and the size of the domal stromatolites decrease westward. The C1 marker of Jacob (1969) is equivalent to the stromatolite marker of Remy (1989a) and the C marker of this report. The C marker is approximately 215 m above the D marker and can be traced for 30 km along Nine Mile Canyon and for 15 km from the canyon southward toward the Roan Cliffs (plate 1). In this report the C marker serves as the boundary between the Sunnyside delta interval and the overlying transitional interval. The C marker is roughly stratigraphically equivalent to the middle marker of Ryder and others (1976) (T.D. Fouch, U.S. Geological Survey, oral commun., 1988).

Jacob's (1969) B marker is approximately 85 m above the stromatolite marker and 45–100 m below the base of the upper member (as defined by the top of the S1 marker unit). The unit is 0.5–4.0 m thick. In most measured sections the B marker is composed of ostracode grainstone (see, for example, unit 129 of measured section 8 in the appendix). In other places, however, the unit consists of ooid grainstone (unit 104, measured section 13) or micrite with oolites and



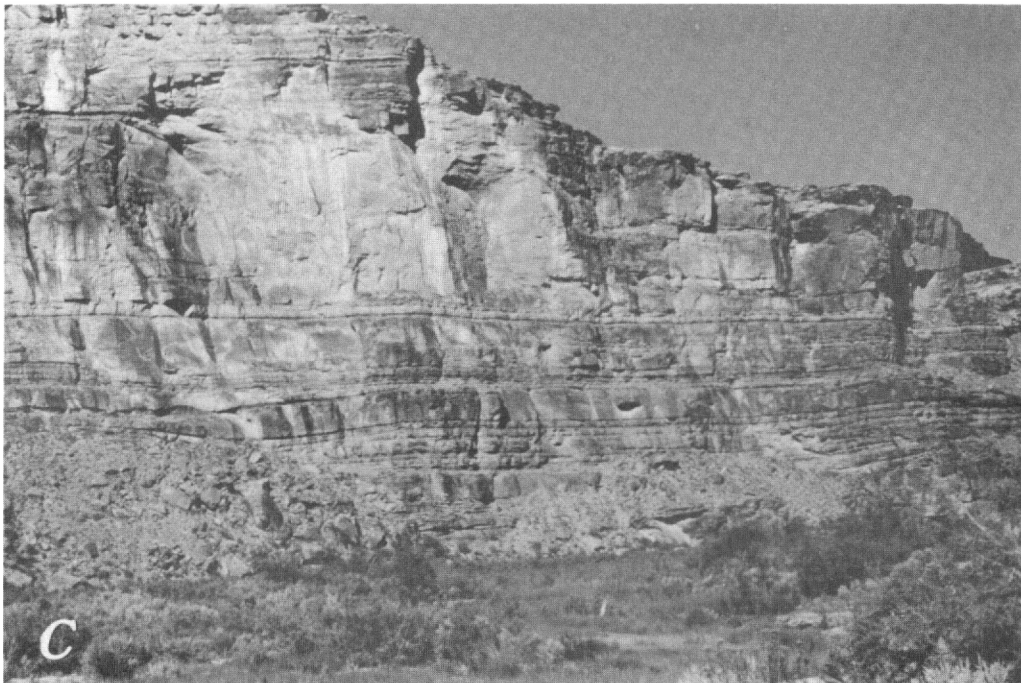
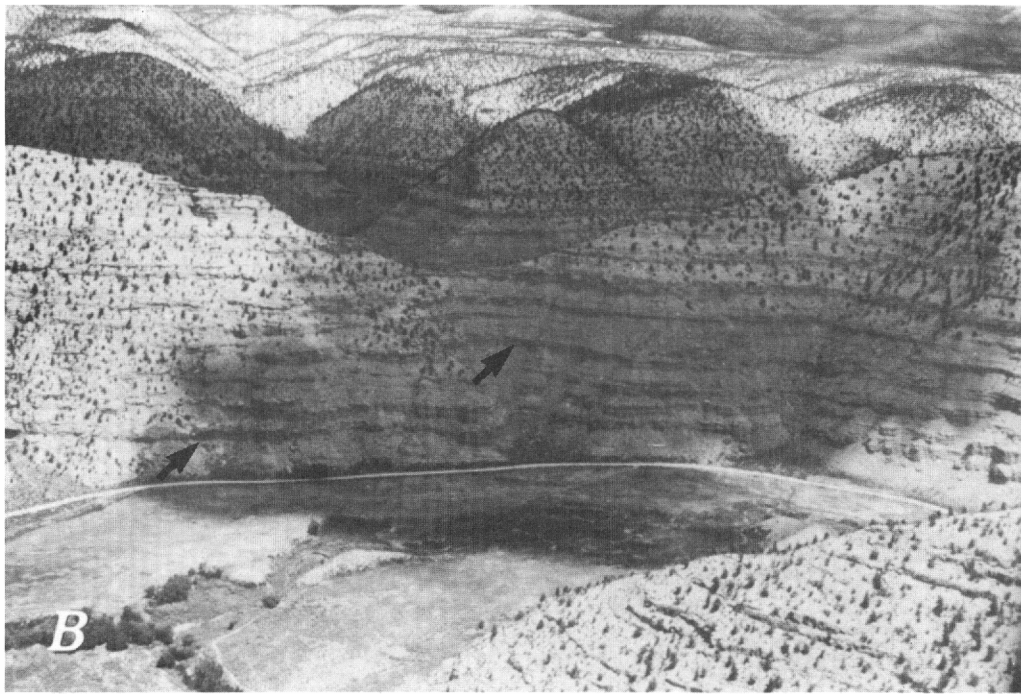
**Figure 5** (above and following pages). Photographs of the Green River Formation. *A*, Large domal stromatolites in the C marker (unit 78, measured section 7, appendix). Ruler (15 cm) for scale. *B*, Sunnyside delta interval in western Nine Mile Canyon immediately west of measured section 11 (fig. 1). At this location the Sunnyside delta interval consists of tabular sandbodies of Sb lithofacies (two indicated with arrows), which are interpreted as meandering delta distributary channels, separated by red and green mudstone, thin sandstone, and limestone that accumulated in subaqueous and subaerial mudflat, crevasse-splay, overbank-sandsheet, and lake-margin carbonate-flat environments. Cliff at extreme right of photograph is 265 m high. *C*, Sunnyside delta interval in eastern Nine Mile Canyon opposite measured section 9 (fig. 1). At this location the Sunnyside delta interval consists of thick amalgamated sandbodies of Sc lithofacies, which are interpreted as stacked distributary mouth bars, and associated mudstone, thin sandstone, and limestone beds that accumulated in subaqueous and subaerial mudflat, crevasse-splay, overbank and shallow-lacustrine sandsheet, and lake-margin carbonate-flat environments. Cliff on left side of photograph is approximately 150 m high. *D*, Horse Bench Sandstone Bed of upper member in Gate Canyon. See measured section 6 (appendix) for detailed description of rocks. Jacob's staff (1.5 m) for scale (arrow). *E*, Upper Roan Cliffs and Sunnyside tar sand quarry. The quarry and all but top 0–30 m of the Roan Cliffs consist of interfingering alluvial to marginal-lacustrine deposits of the Colton and Green River Formations. Thick sandbodies of Sa lithofacies are exposed in the quarry and overlying interval (one sandbody indicated with arrow) and are interpreted as nonsinuuous channels on an upper delta to alluvial plain. The top 0–30 m of the Roan Cliffs at this location consists predominantly of dark mudstone and dolostone and is stratigraphically equivalent to the lower part of the upper member in Nine Mile Canyon. Part of Roan Cliffs shown is approximately 500 m high.

ostracodes and domal stromatolites (unit 120, measured section 14). Similar to the C marker, the B marker can be traced throughout most of Nine Mile Canyon (plate 1).

Recently, I recognized that Bradley's (1931) delta facies in the Nine Mile Canyon area, as redefined to include his basal member, consists of two distinct suites of rocks: (1) a lower, 375-m-thick sequence of marginal-lacustrine rocks informally named the "Sunnyside delta interval" and (2) an upper, 150-m-thick sequence of marginal- to open-lacustrine rocks informally named the "transitional interval" (Remy, 1989a) (fig. 3, section C). The boundary between the units is placed at the C marker, and the B marker subdivides the transitional interval into informal upper and

lower parts. In this report I placed the contact between the transitional interval and the overlying upper member at the top of the S1 marker unit. The S1 marker unit was employed for this purpose because the interval overlying the S1 consists mainly of dark mudstone and dolostone (including the Mahogany ledge), typical rock types in the upper member.

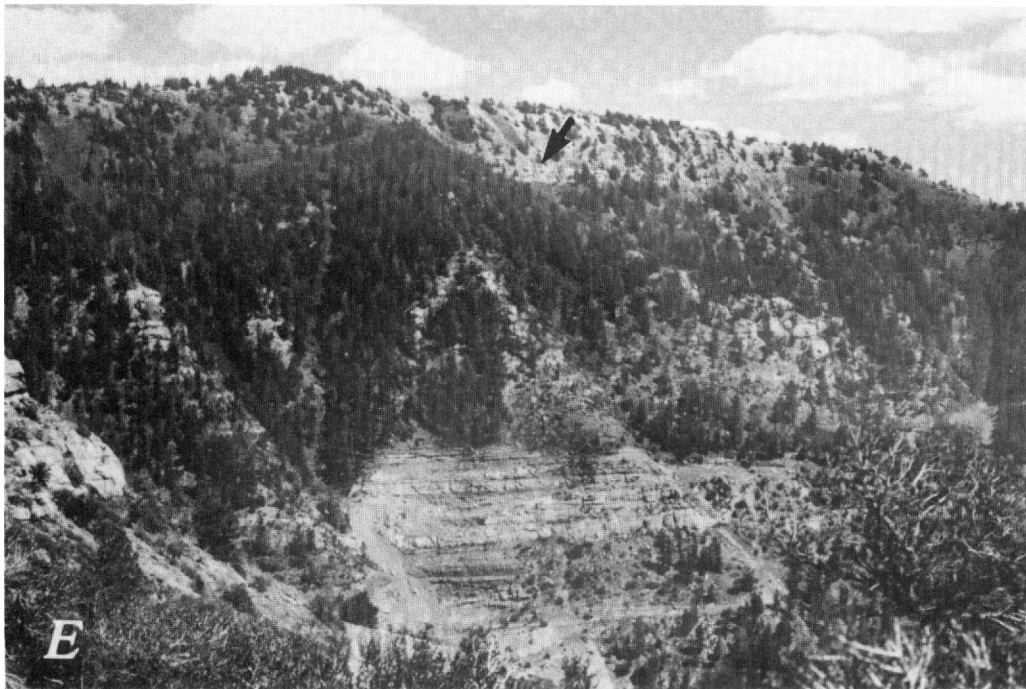
The Sunnyside delta interval was named for the Sunnyside tar sand deposit in the Roan Cliffs. Outcrops of the unit consist of sandstone of the Sb (23.6 percent), Sc (4.0 percent), Se (12.8 percent), and Sf (2.8 percent) lithofacies, red and green mudstone of the Mr (7.8 percent) and Mg (19.0 percent) lithofacies, respectively, carbonate



grainstone, micrite, and stromatolite of the L lithofacies (6.2 percent), very minor (0.5 percent) dark mudstone of the Ia lithofacies, and covered intervals (23.3 percent) probably underlain mainly by mudstone (table 2). These rocks accumulated in meandering delta distributary channel (fig. 5B), delta mouth bar (fig. 5C), crevasse-splay, overbank and shallow-lacustrine sandsheet, subaerial and subaqueous mudflat, lake-margin carbonate-flat, and minor open-lacustrine settings in and adjacent to a large fluvi-ally

dominated delta along the southern shore of Lake Uinta (Remy, 1989a, b, 1991). In this report the term “Sunnyside delta interval” refers to the stratigraphic interval deposited in the Sunnyside delta in the Nine Mile Canyon area. The Sunnyside delta interval and transitional interval of this report are equivalent to Picard’s (1957, 1959) green shale facies.

As its name implies, the transitional interval is a zone of transition between the underlying sand-rich Sunnyside



delta interval and the overlying fine-grained, mudstone- and dolostone-rich upper member. The lower part of the transitional interval contains less sandstone (24.2 percent versus 43.2 percent) and red mudstone (0.4 percent versus 7.8 percent) and more green mudstone (33.2 percent versus 19.0 percent) and limestone (13.7 percent versus 6.2 percent) than the underlying Sunnyside delta interval. Measured sections of the lower half of the transitional interval consist of sandstone of the Sb (9.5 percent), Se

(12.4 percent), and Sf (2.3 percent) lithofacies, green and very minor red mudstone of the Mg (33.2 percent) and Mr (0.4 percent) lithofacies, respectively, carbonate grainstone, micrite, and stromatolite of the L lithofacies (13.7 percent), dark mudstone and dolostone of the Ia lithofacies (0.6 percent), and covered intervals (27.9 percent) probably underlain mainly by mudstone (table 2). The lower part of the transitional interval is illustrated by units 83–163 of measured section 9 (appendix). The upper part of the

transitional interval (that is, above the B marker), on the other hand, contains less green mudstone (23.6 percent versus 33.2 percent) and limestone (5.5 percent versus 13.7 percent) and more dark mudstone and dolostone of the Ia (6.4 percent versus 0.6 percent) and Ib (3.4 percent versus 0 percent) lithofacies than the lower part of the transitional interval. The transitional interval is interpreted to record a major, but gradual, expansion (transgression) of Lake Uinta (Remy, 1989a, b, 1991).

## Upper Member

In Nine Mile Canyon the transitional interval is overlain by approximately 300 m of predominantly fine grained rocks that generally form light-gray covered slopes (figs. 4B, D). Measured sections of this interval consist of gray to brown mudstone, dolostone, kerogenous laminated dolostone (oil shale) and minor sandstone of the Sb (4.6 percent), Sd (5.0 percent), Se (3.8 percent), and Sf (1.5 percent) lithofacies and limestone of the L lithofacies (0.2 percent), and covered intervals (30.8 percent) presumably underlain by mudstone and dolostone (table 2). Measured section 17 (appendix) illustrates these rocks. These typically fine grained rocks are interpreted to have been deposited in generally low energy, nearshore to offshore open-lacustrine settings (table 1) during a period when Lake Uinta was at its maximum extent (Remy, 1991). Several intervals in the member, including the interval capped by the S2 marker unit and the Horse Bench Sandstone Bed, contain significant amounts of sandstone and siltstone interbedded with green mudstone. The sandstone contains a variety of sedimentary structures including hummocky cross-stratification (Remy, 1989c, 1991), trough crossbeds, and ripples (wave, current, and combined flow). The high content of sandstone and siltstone, sedimentary structures indicative of relatively high energy, and the absence of open-lacustrine dolostone suggest that these sandy intervals record periods of major siliciclastic sediment influx into Lake Uinta, perhaps due to decreases in lake level.

Bradley (1931) named these rocks the “shaly facies” (fig. 3, section D). The shaly facies is, in part, equivalent to the upper part of the Bradley’s (1931) Parachute Creek Member in the eastern Uinta basin (fig. 3, section H). Bradley (1931) did not apply the term “Parachute Creek Member” to the rocks overlying his delta facies because the Parachute Creek Member in the eastern Uinta basin consists predominantly of kerogenous dolostone, whereas the interval above the delta facies in the western Uinta basin consists predominantly of mudstone, siltstone, and lesser dolostone.

Dane (1954, 1955) and Ray and others (1956) divided Bradley’s shaly facies into the Parachute Creek Member and the Evacuation Creek Member (fig. 3, section G), which are stratigraphic terms for the upper part of the Green River Formation originally assigned by Bradley (1931) to the

formation in the eastern Uinta basin. Cashion and Donnell (1974) later abandoned the term “Evacuation Creek Member” and reassigned the rocks to the Parachute Creek Member in the eastern Uinta basin. Weiss and others (1990) did not use the terms “Parachute Creek Member” and “shaly facies” and assigned that part of the Green River Formation between the base of the Mahogany oil-shale zone and the base of the saline facies of Dane (1954, 1955) and Ray and others (1956) to the informal upper member. I employ the stratigraphic terminology of Weiss and others (1990) for this part of the Green River Formation and place the base of the upper member at the top of the S1 marker unit, which is also the base of the Mahogany ledge.

The most widespread outcrop and subsurface marker in the Green River Formation is the Mahogany oil-shale bed (Cashion, 1967; Fouch and Cashion, 1979). In the study area this unit is 11–35 m above the base of the upper member (as defined by the top of the S1 marker unit) and consists of 1–2 m of black, highly kerogenous, laminated dolostone (see, for example, units 12–15 of measured section 10 in the appendix). The Mahogany bed is the richest and most prominent oil shale in the Mahogany ledge, which consists of several resistant rich oil-shale beds (Cashion, 1967). This interval was named the Mahogany ledge by Bradley (1931, p. 23) because polished surfaces of the rock resemble old mahogany.

The S2 marker unit of Fouch and others (1976) is 30–60 m above the S1 marker unit. In and near Gate Canyon the S2 is a thin (1 m), ledge-forming, very fine grained sandstone containing ripples (wave, current, and combined flow), planar laminations, and hummocky cross-stratification (Remy, 1989c) (see, for example, unit 17 of measured section 15, appendix) and green mudstone in places. The unit consists of several stacked and amalgamated hummocky cross-stratified storm deposits that accumulated in an open-lacustrine environment (Remy, 1989c, 1991). Toward the east, the S2 thickens and is much coarser grained. As noted above, the S2 marker unit is equivalent to the 3-bed of Ray and others (1956). The S2 marker unit can be traced regionally along the south flank of the basin (Fouch and others, 1976).

In outcrops in the study area the most prominent unit in the upper member is a plateau-forming interval of sandstone and mudstone (figs. 4C, D, 5D) that Bradley (1931, p. 16) named the “Horse Bench Sandstone Lentil.” Subsequent workers (Dane, 1955; Cashion, 1967; Fouch, 1975) referred to this unit as the “Horse Bench Sandstone Bed.” In the study area the resistant Horse Bench Sandstone Bed forms a broad smooth plateau that is overlain and underlain by generally poorly exposed, slope-forming, mudstone and dolostone (fig. 4C, D). The base of the Horse Bench Sandstone Bed is approximately 150 m above the base of the upper member (that is, the top of S1 marker unit). It is a 10–20-m-thick interval consisting of greenish-gray to brown mudstone, siltstone, and sandstone (fig. 5D;



measured sections 5 and 6 and units 69–73 of measured section 17, appendix). Sedimentary structures include wave and current ripples, trough crossbeds, syneresis cracks, and burrows. The top of the Horse Bench Sandstone Bed and equivalent horizons are equivalent to the upper marker of Fouch (1975), which can be traced throughout most of the basin subsurface (Fouch and Cashion, 1979; Fouch, 1981).

Dane (1954, 1955) and Ray and others (1956) described two tuff zones above the Horse Bench Sandstone Bed. In the area of Gate Canyon, however, the only prominent stratigraphic marker I encountered in the upper part of the upper member was a tuff bed about 80 m below the top of the member. The tuff is approximately 20–35 cm thick, weathers yellow, and is characterized by abundant biotite crystals in the lower half of the bed (unit 86 of measured section 17, appendix).

In this study the top of the upper member is placed approximately 150 m above the base of the Horse Bench Sandstone Bed at the first occurrence upward of substantial sandstone beds above the Horse Bench Sandstone Bed. The contact is also marked by a change in the weathered color of the rocks. The upper member forms light-gray slopes, whereas overlying rocks weather light brown. In the area of Nine Mile Canyon, the upper member of the Green River Formation is overlain by the saline facies of the Green River Formation of Weiss and others (1990) and by the sandstone and limestone facies of Bryant (1990). The saline facies of Weiss and others (1990) is equivalent to the saline facies of the Uinta Formation of Dane (1954, 1955) and Ray and others (1956).

## LITHOSTRATIGRAPHY OF THE GREEN RIVER FORMATION: ROAN CLIFFS

The upper 500 m of the Roan Cliffs near the Sunnyside tar sand deposit consists of a 470–500-m-thick sequence containing abundant sandstone and mudstone and rare limestone overlain by a 0–30-m-thick sequence containing abundant dolostone and green mudstone (fig. 5E; measured sections 1 and 2, appendix; plate 1). Measured sections of the lower sand-rich sequence consist of sandstone of the Sa (37.7 percent), Sb (14.8 percent), Se (8.8 percent), and Sf (0.4 percent) lithofacies, red and green mudstone of the Mr (9.7 percent) and Mg (9.7 percent) lithofacies, respectively, limestone of the L lithofacies (2.9 percent), dark mudstone of the Ia lithofacies (0.6 percent), and covered intervals (15.4 percent) that are probably underlain mainly by mudstone (table 2). These rocks are interpreted to have been deposited in nonsinuuous channels, meandering delta distributary channels, crevasse splays, overbank sandsheets, subaerial and subaqueous interchannel mudflats, and rare lake-margin carbonate flats in a lower delta plain to alluvial setting (table 1, plate 1).

A measured section of the dolostone-rich interval at the top of the Roan Cliffs (units 81–95 of measured section

2, appendix) consists of sandstone of the Se lithofacies (4.4 percent), green mudstone of the Mg lithofacies (24.3 percent), carbonate grainstone and micrite of the L lithofacies (15.7 percent), and laminated and structureless dolostone and gray to brown mudstone of the Ia (7.8 percent) and Ib (47.8 percent) lithofacies. These rocks are interpreted to have been deposited in overbank and shallow-lacustrine sandsheet, subaqueous mudflat, lake-margin carbonate-flat, and open-lacustrine environments (table 1) (Remy, 1991). The lower green mudstone- and limestone-rich part of this sequence is interpreted to have accumulated in a shallow nearshore-lacustrine setting, and the upper dolostone-rich part of the sequence is interpreted to have accumulated in a proximal to distal open-lacustrine setting (plate 1).

The stratigraphic sequence that crops out in the upper Roan Cliffs near the Sunnyside tar sand deposit has been variously placed in the upper part of the Colton or Wasatch Formation and the lower part of the Green River Formation (Holmes and others, 1948; Williams, 1950; Abbott and Liscomb, 1956; Covington, 1975; Banks, 1981), in the upper black shale facies of Picard (1955, 1959) (Hendel, 1957; Murany, 1964), and in the lower part of the main body of the Green River Formation (Jacob, 1969; Ryder and others, 1976; Campbell and Ritzma, 1979). Recently, Weiss and others (1990) mapped the uppermost fine-grained sequence at the top of the cliffs as the upper member of the Green River Formation, the 200-m-thick sequence underlying the upper member as the middle member of the Green River Formation, and the underlying rocks as the Colton Formation.

Most workers (Jacob, 1969; Fouch and others, 1976, fig. 2; J.A. Campbell, Oklahoma Geological Survey, written commun., 1986; Weiss and others, 1990) agree that the Mahogany oil-shale bed is near the top of the Roan Cliffs. The same oil shale was also mapped by Winchester (1923, plate 16). In the Roan Cliffs above the Sunnyside tar sand quarry the Mahogany oil-shale bed is approximately 80 cm thick and consists of laminated, kerogenous dolostone (oil shale), structureless dolostone, and brown laminated dolostone or shale (basal 80 cm of unit 83, measured section 2, appendix). The Mahogany is underlain by limestone and overlain by green mudstone.

The presence of the Mahogany oil-shale bed at the top of the Roan Cliffs allows the stratigraphic section at the Roan Cliffs to be correlated with the Green River Formation in the area of Nine Mile Canyon (plate 1). This correlation demonstrates that the dolostone- and green-mudstone-rich interval at the top of the Roan Cliffs is stratigraphically equivalent to part of the lower part of the upper member of the Green River Formation in the Nine Mile Canyon area (Weiss and others, 1990). The underlying interfingering Green River and Colton Formations, which contain the Sunnyside tar sand deposit, are stratigraphically equivalent to the lowermost part of the upper member, all of the transitional interval, and the upper half of the Sunnyside

delta interval. The facts that lithofacies characteristic of the lower delta plain assemblage (that is, lithofacies L, Mg, and Sb) are more abundant in the upper half of the interfingering Colton and Green River Formations than in the lower half and that lithofacies characteristic of the upper delta—alluvial plain assemblage (that is, lithofacies Mr and Sa) are more abundant in the lower half of the interval than in the upper half (plate 1) indicate that the expansion (transgression) of Lake Uinta suggested by the transitional interval in Nine Mile Canyon also affected sedimentation in the area that is now the Roan Cliffs.

As noted above, Weiss and others (1990) mapped the rocks above the Mahogany oil-shale bed at the Roan Cliffs near Sunnyside as the upper member of the Green River Formation and the sandstone-rich sequence below the Mahogany as the middle member of the Green River Formation underlain by the Colton Formation. The middle member as mapped by Weiss and others (1990) is approximately 200 m thick at this location. Measured sections 1 and 2 of this report (appendix) show, however, that there is no easily identifiable consistent lithologic break in the stratigraphic section that can be employed to distinguish the middle member from the Colton Formation. Moreover, lithofacies Sa, which is typical of inferred upper delta plain to alluvial deposits of the Colton Formation, is present within 100 m of the top of the Roan Cliffs (see, for example, unit 63 of measured section 2). Rather than having a sharp break between the Green River and Colton Formations, the upper Roan Cliffs beneath the fine-grained upper member of the Green River Formation consist of extensive interfingering of rocks typical of the Green River Formation and those typical of the Colton Formation. Therefore, I made no attempt to differentiate the middle member of the Green River Formation from the Colton Formation, and I refer to the entire 475–500-m-thick sequence beneath the upper member as the “interfingering Green River and Colton Formations” on plate 1.

The S1 and S2 marker units and limestone markers B and C pinch out or lose their identity somewhere between the Roan Cliffs (measured sections 1 and 2) and measured section 14, which is approximately 11 km north of the Roan Cliffs (fig. 1, plate 1). I could not confidently identify the carbonate marker unit in the Roan Cliffs beneath measured sections 1 and 2. The Mahogany oil-shale bed is, therefore, the only stratigraphic marker in the Green River Formation that can be confidently identified along the Roan Cliffs near the Sunnyside tar sand quarry.

## CHRONOSTRATIGRAPHY OF THE GREEN RIVER FORMATION

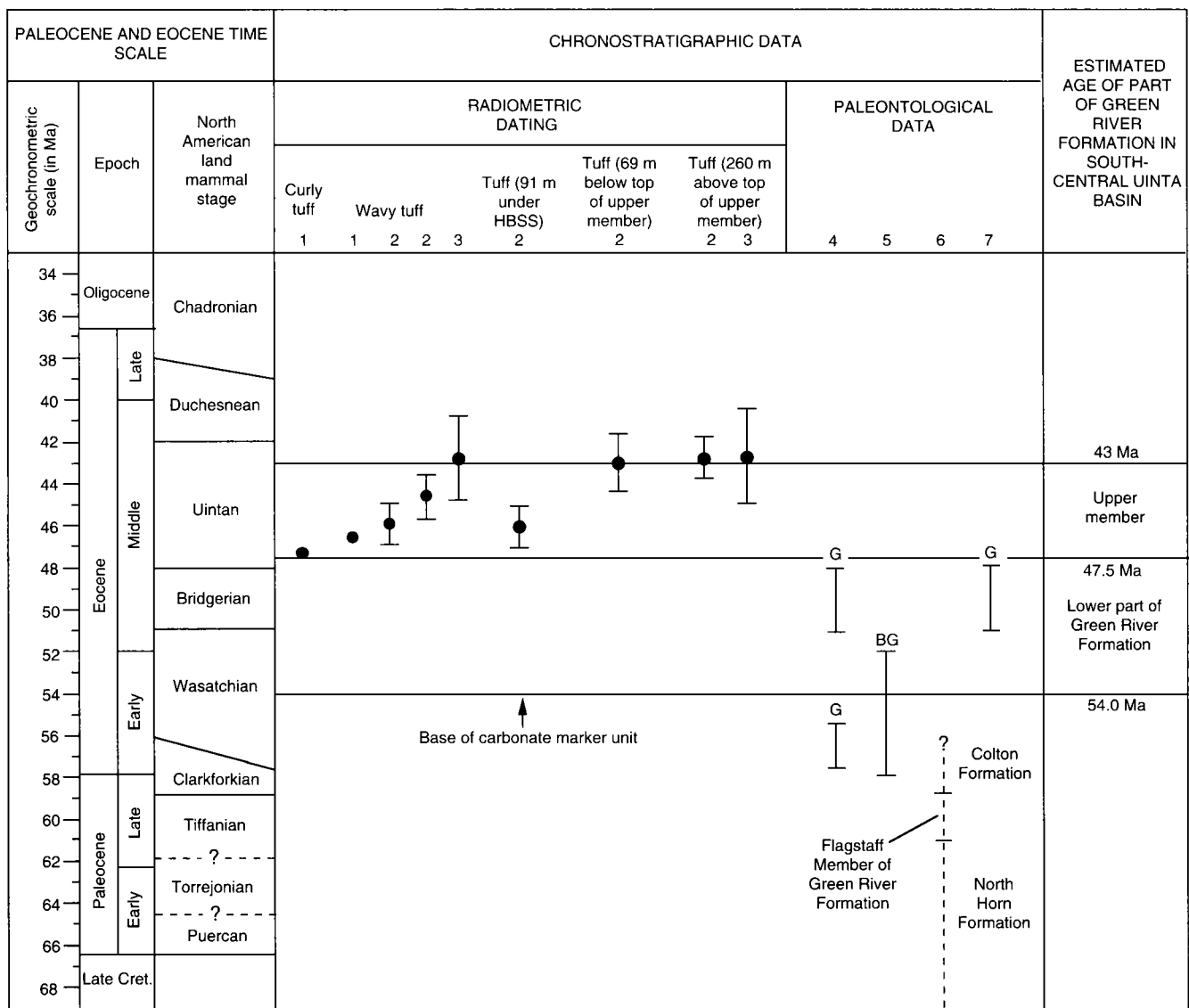
Unlike the upper member, the lower part of the Green River Formation (carbonate marker unit, Sunnyside delta interval, and transitional interval) does not contain tuffs that

can be radiometrically dated; however, paleontological data can be used to roughly constrain the age of these rocks (fig. 6). Analysis of microfossils suggests that the Paleocene-Eocene boundary is in the upper third of the Colton Formation on the south flank of the basin (Ryder and others, 1976, p. 497). This interpretation is supported by the presence of late Paleocene nonmarine molluscs in the underlying Flagstaff Member of the Green River Formation in Price Canyon (Fouch and others, 1987). In the southern Uinta basin the Paleocene-Eocene boundary is approximately 550 m below the top of the carbonate marker unit (Fouch, 1981). In the study area the interval between the top of the carbonate marker unit and the top of the transitional interval is approximately 550 m thick. The 1,100 m of rocks between the Paleocene-Eocene boundary, which Berggren and others (1985) placed at approximately 58 Ma, and the top of the transitional interval, which radiometric dates on tuffs place at approximately 47.5 million years, accumulated in about 10.5 million years. These data suggest a rock accumulation rate of approximately 105 m per million years. This estimate is supported by Bradley (1929), who estimated that fluvial rocks above and below the Green River Formation accumulated at a rate of about 1 ft per 3,000 years (101.6 m per million years). Assuming that the generally sand-rich lower part of the Green River Formation accumulated at about the same rate as the underlying rocks, then the 700 m of the lower part of the Green River Formation (base of carbonate marker unit to top of transitional interval) accumulated in about 6.5 million years, and the age of the base of the main body of the Green River Formation in the area of Nine Mile Canyon is very roughly 54 Ma.

The upper member contains several tuffs that serve as regional stratigraphic markers. Radiometric dating of some of these tuffs (Mauger, 1977; O'Neill, 1980; O'Neill and others, 1981; Bryant and others, 1990) provides chronostratigraphic control on the upper member (fig. 6).

The curly tuff is between the S1 marker unit and the Mahogany oil shale bed (O'Neill, 1980) (fig. 3, section C). The tuff is 2.5–46 cm thick and characterized by undulatory upper and lower contacts and contorted bedding (Cashion, 1967, p. 16). A mean  $^{40}\text{Ar}/^{39}\text{Ar}$  date on biotites from the tuff in Gate Canyon was initially reported by O'Neill (1980) as  $46.2 \pm 0.7$  Ma. O'Neill and others (1981) subsequently reported a date of 47.2 Ma for the same tuff. The latter date presumably represents reevaluation of the data originally reported in O'Neill (1980) and is therefore the date used in this study. The curly tuff lies a little above the S1 marker unit and is therefore a little younger than the base of the upper member; thus the age of the base of the member is approximately 47.5 Ma in the Gate Canyon area.

The wavy tuff is approximately 55 m above the Mahogany oil shale bed in Gate Canyon (O'Neill, 1980, fig. 32). The tuff has an average thickness of 30 cm (O'Neill, 1980) and is characterized by intercalated stringers of



#### EXPLANATION

HBSS, Horse Bench Sandstone Bed.

G, lower part of Green River Formation (carbonate marker unit, Sunnyside delta interval, and transitional interval).

BG, basal Green River Formation (beneath carbonate marker unit).

#### SOURCES OF DATA

- <sup>40</sup>Ar/<sup>39</sup>Ar radiometric date on tuff (O'Neill and others, 1981).
- Recalibration of K/Ar radiometric date on tuff of Mauger (1977), as reported in Krishtalka and others (1987).
- Fission-track ages of zircons in tuff (Bryant and others, 1990, table 1).
- Bridgerian or possibly latest Graybullian (early Wasatchian) turtles in Sunnyside delta interval in Nine Mile Canyon (identified by J.H. Hutchison, written commun., 1989).
- Early Eocene palynomorphs in attrital coal in basal Green River Formation beneath carbonate marker unit, Indian Canyon (Fouch and others, 1976, p. 371).
- Analysis of palynomorphs, ostracodes, charophytes, and mollusks indicates that age of basal part of North Horn Formation is Late Cretaceous (Maastrichtian), upper part of the North Horn Formation is middle to late Paleocene, and Flagstaff Member of the Green River Formation in Price Canyon is late Paleocene (Fouch and others, 1987).
- Bridgerian fauna is in Green River Formation, 82 m below Mahogany oil-shale bed in eastern Uinta basin (Krishtalka and others, 1987).

**Figure 6.** Chronostratigraphy of part of the Green River Formation in the south-central part of the Uinta basin. Time scale from Berggren and others (1985).

marlstone that accentuate the wavy bedding surfaces produced by plastic flow or differential compaction (Cashion, 1967, p. 16). O'Neill (1980) obtained a mean <sup>40</sup>Ar/<sup>39</sup>Ar

date of 46.2±0.5 Ma from biotite separates from this tuff. O'Neill and others (1981) subsequently reported a date of 46.7 Ma for the same tuff. The latter date is used in this

study for the reason discussed earlier. Recalibration of K/Ar dates on biotites from the wavy tuff in Gate Canyon (Mauger, 1973; his sample RLM-7-70) and Indian Canyon (his sample RLM-2-70) yielded dates of  $46.0 \pm 0.9$  and  $44.7 \pm 1.0$  Ma, respectively (reported in Krishtalka and others, 1987, table 4.1). Bryant and others (1990, table 1) obtained a zircon fission-track age of  $42.3 \pm 2.0$  Ma for the wavy tuff in Indian Canyon (their locality 23). They noted, but did not offer an explanation for, the discrepancy between their results and those of Mauger (1977) and O'Neill and others (1981). Excluding the anomalous zircon fission-track age of Bryant and others (1990), the mean age of the wavy tuff is approximately 46.2 Ma, in reasonable agreement with a presumed age of 47.5 Ma for the base of the upper member based on the curly tuff.

Recalibration of Mauger's (1977) K-Ar date for an unnamed tuff (his sample RLM-2-69) 91 m below the base of the Horse Bench Sandstone Bed in Dane's (1955) Indian Canyon section yielded an age of  $45.9 \pm 0.9$  Ma (recalibrated date reported in Krishtalka and others, 1987, table 4.1). This tuff is 7 m above the wavy tuff, which is 98 m below the Horse Bench Sandstone Bed in Dane's (1955) Indian Canyon section (Mauger, 1977, table 1). Recalibration of Mauger's (1977) K-Ar date for a tuff (his sample RLM-1-69) 69 m below the top of Dane's (1954, 1955) Evacuation Creek Member (upper part of upper member of this report) in Indian Canyon yielded an age of  $43.1 \pm 1.3$  Ma (Krishtalka and others, 1987, table 4.1).

Recalibration of Mauger's (1977) K-Ar date on a tuff in Indian Canyon (his sample RLM-8-70) that is about 19 m below the top of Dane's (1954, 1955) limestone-sandstone facies of the Uinta Formation yielded an age of  $42.8 \pm 1.0$  Ma (Krishtalka and others, 1987, table 4.1). This tuff is approximately 260 m above the top of the upper member as defined in this study. Bryant and others (1990, table 1) obtained a zircon fission-track age of  $42.8 \pm 2.2$  Ma for the same tuff in Indian Canyon (their locality 22). The top of the upper member is thereby bracketed by ages of tuffs above the wavy tuff of  $45.9 \pm 0.9$  Ma and  $43.1 \pm 1.3$  Ma and by two age estimates of about 42.8 Ma for a tuff substantially above the top of the member. These data suggest an age of about 43 Ma for the top of the upper member in the study area.

To summarize, analysis of published paleontological and radiometric age data from the Green River Formation suggests ages of about 54.0 Ma for the base of the carbonate marker unit, about 47.5 Ma for the contact between the transitional interval and the upper member, and about 43 Ma for the top of the upper member in the study area. This interval extends from the late early Eocene to the upper half of the middle Eocene and from the middle Wasatchian to the late Uintan North American land mammal stages (time scale of Berggren and others, 1985) (fig. 6). The conclusion that the interval between the base of the carbonate marker unit and the top of the transitional interval spans the late

Wasatchian, all of the Bridgerian, and part of the early part of the Uintan North American land mammal stages is supported by (1) the presence of Bridgerian or latest Graybullian (early Wasatchian) turtles in the Sunnyside delta interval (J.H. Hutchison, University of California, Berkeley, written commun., 1989), (2) a Bridgerian mammal fauna collected 82 m below the Mahogany oil shale bed in the eastern Uinta basin (Krishtalka and others, 1987, p. 101), and (3) early Eocene palynomorphs in attrital coal beneath the carbonate marker unit in Indian Canyon (Fouch and others, 1976, p. 371).

## SUMMARY AND CONCLUSIONS

1. The carbonate marker unit (Fouch and others, 1976; Ryder and others, 1976) marks the base of the main body of the Eocene part of the Green River Formation in the south-central part of the Uinta basin. It consists of approximately 130 m of ostracode and ooid grainstone and micrite, green, gray, and brown mudstone, sandstone and siltstone, and uncommon dark laminated mudstone and kerogenous laminated dolostone (oil shale). These rocks accumulated along the fluctuating southern shore of Lake Uinta in lake-margin carbonate-flat, subaqueous mudflat, crevasse-splay, overbank and shallow-lacustrine sandsheet, delta distributary channel, and proximal open-lacustrine settings. Hendel's (1957) upper black shale of the Peters Point gas field is equivalent to the carbonate marker unit, and the distinct change in the weathered color of the rocks from light gray below to light brown above that marks the top of the carbonate marker unit in surface exposures is equivalent to the carbonate marker of Ryder and others (1976) in the subsurface rocks in the basin.

2. In the area of Nine Mile Canyon the delta facies of Bradley (1931), as redefined to include his basal member, consists of two distinct suites of rocks: (1) a lower, 375-m-thick sequence of marginal-lacustrine rocks informally named the Sunnyside delta interval and (2) an upper, 150-m-thick sequence of marginal- to open-lacustrine rocks informally named the transitional interval. In the Nine Mile Canyon area the Sunnyside delta interval consists of sandstone, red and green mudstone, and shallow-water carbonate rocks deposited in a large fluvially dominated delta system along the southern shore of Lake Uinta. The transitional interval is characterized by an upward increase from the base of the unit in the amount of open-lacustrine dolostone, kerogenous laminated dolostone (oil shale), and dark mudstone and a decrease in the amount of marginal-lacustrine green mudstone and shallow-water limestone. These lithologic changes record a major, but gradual, expansion of Lake Uinta.

3. Three transgressive shallow-water limestone units in the Sunnyside delta interval and transitional interval serve as local chronostratigraphic markers. These limestone units, which were originally identified by Jacob (1969), are

(from base to top) (1) the D marker, which is near the middle of the Sunnyside delta interval, (2) the C marker, which marks the top of the Sunnyside delta interval, and (3) the B marker, which is near the middle of the transitional interval. The boundary between the transitional interval and the overlying upper member of the Green River Formation is placed at the top of the S1 marker unit of Fouch and others (1976).

4. The upper member overlies the transitional interval in the area of Nine Mile Canyon and consists of approximately 300 m of dark mudstone, dolostone, and kerogenous laminated dolostone (oil shale) and minor sandstone and siltstone that accumulated in a relatively low energy open-lacustrine setting during a period when Lake Uinta was at its maximum size. The member contains several regional stratigraphic markers: (1) the Mahogany oil-shale bed, a 1–2-m-thick kerogenous laminated dolostone (oil shale) 18–32 m above the base of the upper member, (2) the S2 marker unit (Fouch and others, 1976), (3) the Horse Bench Sandstone Bed, a 10–20-m-thick interval of sandstone, siltstone, and greenish mudstone approximately 150 m above the base of the member, and (4) a 20–35-cm-thick unnamed tuff 80 m below the top of the upper member.

5. The upper Roan Cliffs near the Sunnyside tar sand quarry consist of several hundred meters of sandstone, red and green mudstone, and very minor limestone deposited in a lower delta plain to alluvial setting overlain, in places, by a 30-m-thick interval of limestone, green mudstone, dolostone, and minor sandstone deposited in shallow-nearshore and open-lacustrine settings. The presence of the Mahogany oil-shale bed near the top of the Roan Cliffs demonstrates that the top 0–30 m of the cliff is stratigraphically equivalent to the lower part of the upper member of the Green River Formation in Nine Mile Canyon and that the underlying rocks (including the tar sands), which represent a zone of interfingering between the marginal- and open-lacustrine Green River Formation and the alluvial Colton Formation, are stratigraphically equivalent to the lowermost upper member, the transitional interval, and the upper Sunnyside delta interval in the Nine Mile Canyon area.

6. Analysis of published paleontological data and  $^{40}\text{Ar}/^{39}\text{Ar}$ , K/Ar, and zircon fission-track dates from tuffs in the upper member suggests ages of approximately 54 Ma, 47.5 Ma, and 43 Ma for the base of the carbonate marker unit, the top of the transitional interval, and the top of the upper member, respectively, in the study area.

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APPENDIX—MEASURED STRATIGRAPHIC SECTIONS

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A. Thickness, location, and stratigraphic markers of measured stratigraphic sections

[Leader (-) indicates marker is below or above section; query (?) indicates marker not identified]

Section number <sup>1</sup>	Thickness (meters)	Location <sup>2</sup>	Position of stratigraphic markers (in meters from base of section)											
			Lower part of Green River Fm. <sup>3</sup>					Upper member						
			Top carbonate marker unit	Base D marker	Base C marker	Base B marker	Top S1 marker unit	Base Mahogany oil-shale bed	Base S2 marker unit	Base Horse Bench SS Bed	Base tuff bed	Top upper member		
1	504.7	Roan Cliffs. Base: NE1/4NE1/4, sec. 9, T. 14 S., R. 14 E. Top: SE1/4SW1/4, sec. 3, T. 14 S., R. 14 E., at top of cliff.	—	—	—	—	—	—	—	—	—	—	—	—
2	487.5	Roan Cliffs. Sec. 4, T. 14 S., R. 14 E., along road to Bruin Point, base at 8,800 ft (below north tar sand quarry), top at top of road.	—	—	—	—	—	463.3	—	—	—	—	—	—
4	172.6	Cottonwood Canyon. Base: NE1/4SW1/4, sec. 31, T. 12 S., R. 16 E. Top: NE1/4NE1/4, sec. 6, T. 13 S., R. 16 E.	—	—	—	72.1	124.2	155.3	163.3	—	—	—	—	—
5	7.6	Left fork of Indian Canyon (US Route 191). NW1/4NE1/4, sec. 22, T. 6 S., R. 7 W.	—	—	—	—	—	—	—	0	—	—	—	—
6	11.7	Gate Canyon. SE1/4NE1/4NE1/4, sec. 17, T. 11 S., R. 15 E.	—	—	—	—	—	—	—	0	—	—	—	—
7	392.9	Junction of Gate and Nine Mile Canyons. Base: NE1/4SE1/4, sec. 32. Top: NE1/4SW1/4, sec. 29; both T. 11 S., R. 15 E.	—	—	177.4	255.9	355.9	381.3	391.2	—	—	—	—	—
8	363.3	Nine Mile Canyon. Base: SW1/4NW1/4, sec. 4, T. 12 S., R. 14 E. (near abandoned farmhouse). Top: top of ridge due north of base at elevation of 7262 ft.	—	14.1	237.0	319.9	—	—	—	—	—	—	—	—
9	342.0	Nine Mile Canyon. Base: SE1/4SW1/4, sec. 8. Top: NW1/4SW1/4, sec. 17; both T. 12 S., R. 16 E.	—	—	125.0	202.6	300.3	311.5	336.9	—	—	—	—	—
10	63.0	Gate Canyon. Base: NW1/4SE1/4NE1/4, sec. 20, T. 11 S., R. 15 E., at road level. Top: NE1/4SW1/4NW1/4, sec. 20, T. 11 S., R. 15 E.	—	—	—	—	13.0	34.7	54.7	—	—	—	—	—
<sup>4</sup> 11	264.3	Nine Mile Canyon. Base: SE1/4NW 1/4, sec. 15, T. 12 S., R. 13 E. Top: 350 m (horizontally) northwest of base at top of ridge (7,426 ft elevation)	105.7	—	—	—	—	—	—	—	—	—	—	—
13	260.0	Junction of Nine Mile and North Franks Canyons. Base: NW1/4NW1/4, sec. 1, T. 12 S., R. 16 E. Top: SE1/4SE1/4, sec. 35, T. 11 S., R. 16 E.	—	—	76.4	159.5	203.8	218.1	252.5	—	—	—	—	—
14	279.0	Dry Canyon. Base: SW1/4, sec. 5, T. 13 S., R. 15 E. Top: approximately 450 m (horizontally) northwest of base near 7,400 ft contour.	—	—	101.3	175.9	?	244.0	255.7	—	—	—	—	—
15	16.3	Base: NE1/4NE1/4NE1/4, sec. 20, T. 11 S., R. 15 E. Top: NW1/4NW1/4NW1/4, sec. 21, T. 11 S., R. 15 E.	—	—	—	—	—	—	15.3	—	—	—	—	—
16	492.7	Nine Mile Canyon. Base: SE1/4SE1/4, sec. 11, T. 12 S., R. 13 E. Top: NE1/4NW1/4, sec. 11, T. 12 S., R. 13 E.	0	161.6	370.0	460.5	—	—	—	—	—	—	—	—
17	307.1	East Fork of Blind Canyon. Base: SW1/4, sec. 35. Top: NW1/4, sec. 24; both in T. 11 S., R. 15 E.	—	—	—	—	12.0	44.0	72.2	162.5	227.8	307.1	—	—
18	272.4	Upper Water Canyon. Base: SW1/4, sec. 27. Top: SE1/4, sec. 15; both in T. 11 S., R. 15 E.	—	—	—	—	24.9	53.4	85.7	192.3	272.2	—	—	—
19	277.2	Gate Canyon. Base: SE1/4, sec. 20. Top: SE1/4 sec. 17; both in T. 11 S., R. 15 E.	—	—	—	—	49.4	75.2	111.1	222.1	276.9	—	—	—

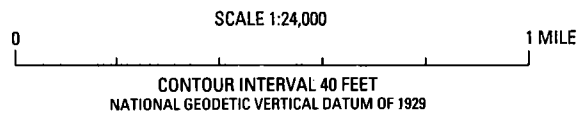
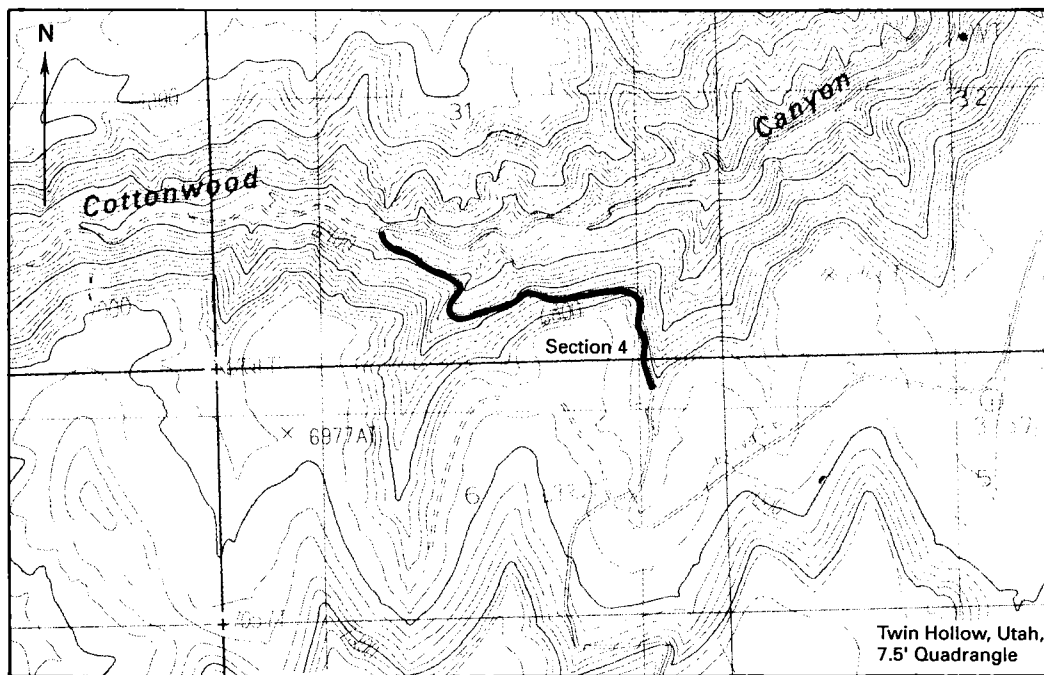
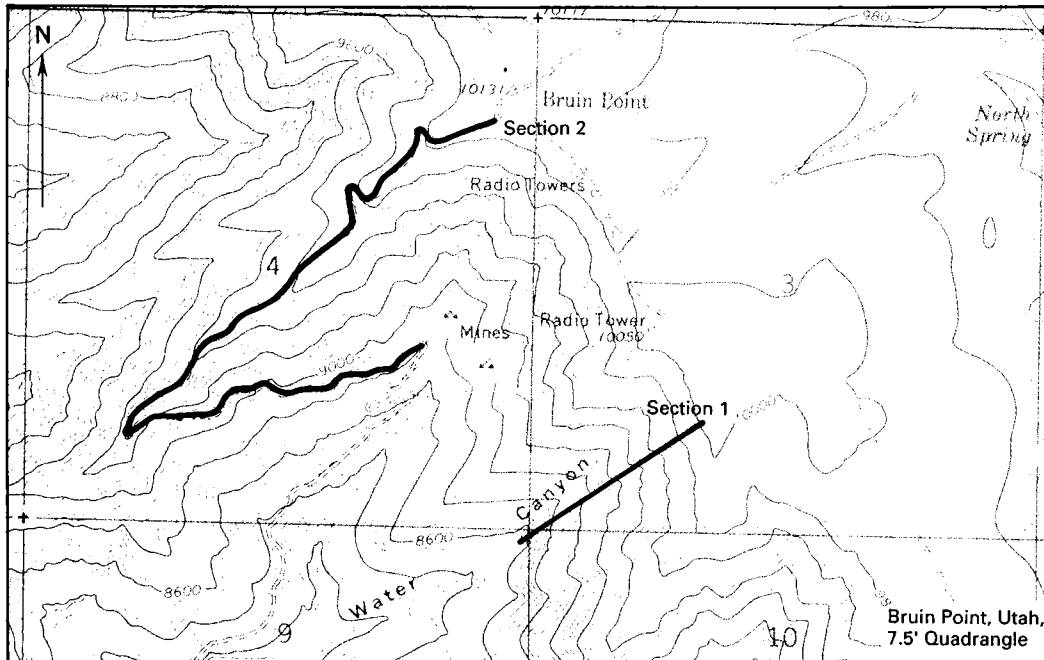
<sup>1</sup> Measured section 2 is a composite section of sections 2, 3, and 12. Measured sections 17, 18, and 19 were measured by Xudong Ying (Louisiana State University, written communication, 1988). Because of the similarity of sections 17, 18, and 19 only section 17 is published in this report.

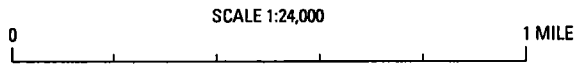
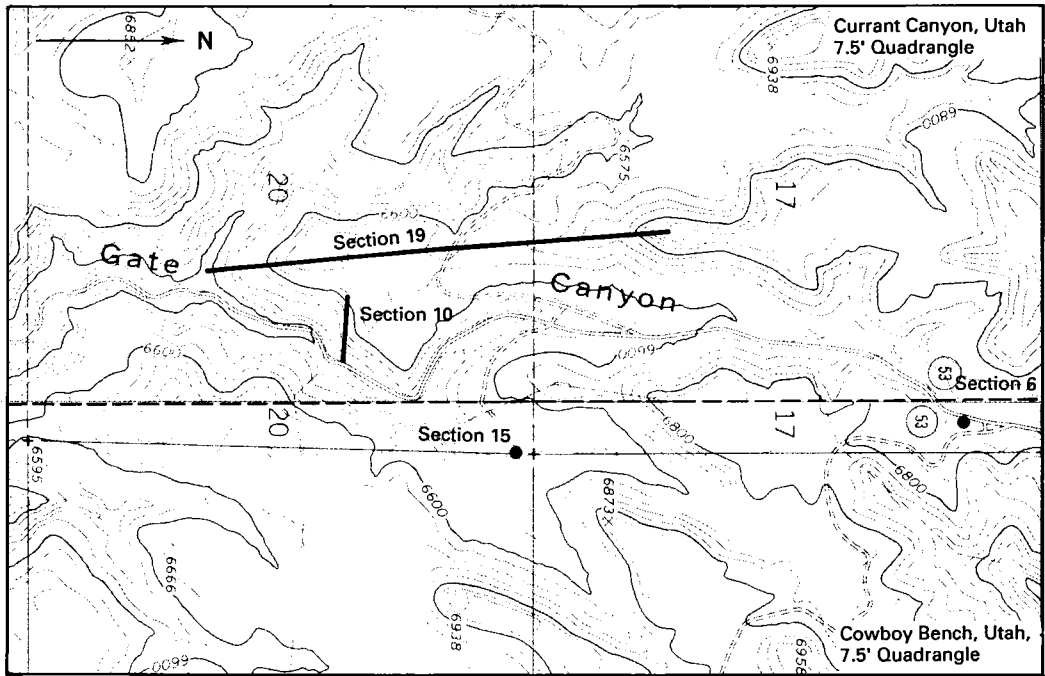
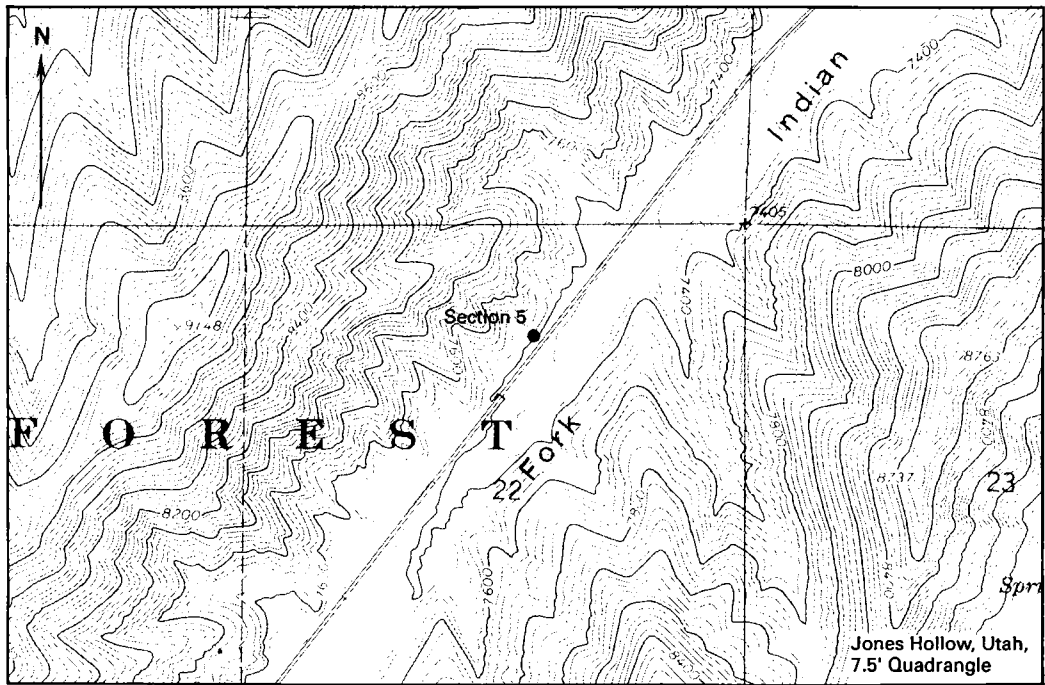
<sup>2</sup> Locations of measured sections are indicated on topographic maps following.

<sup>3</sup> Lower part of Green River Formation = carbonate marker unit, Sunnyside delta interval, and transitional interval.

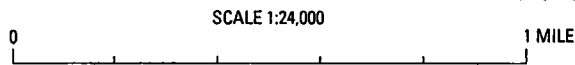
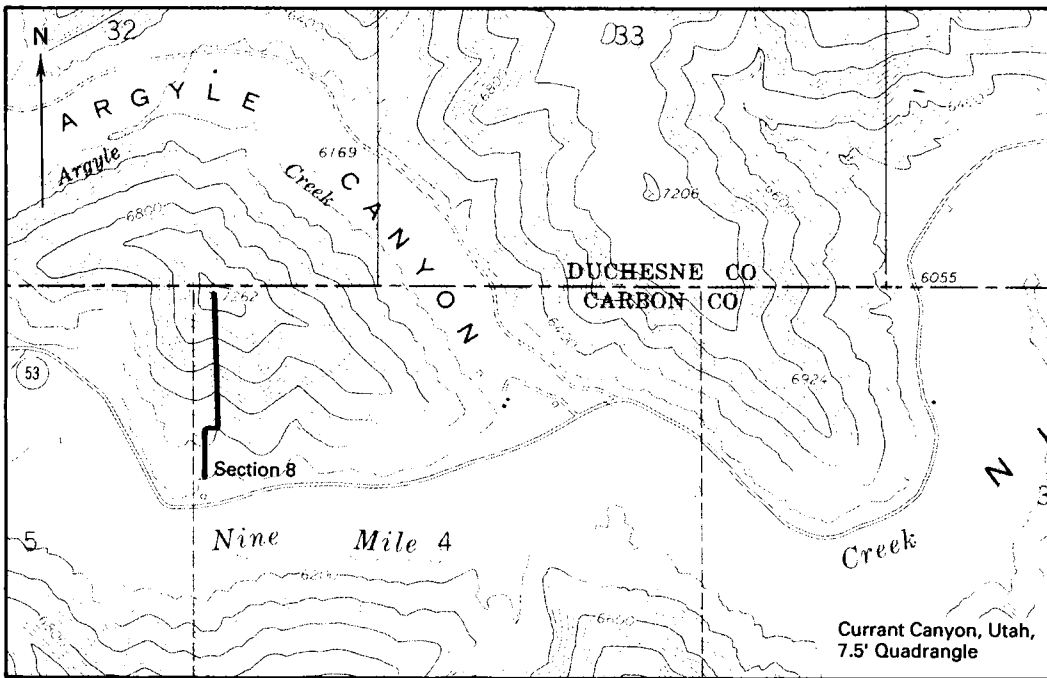
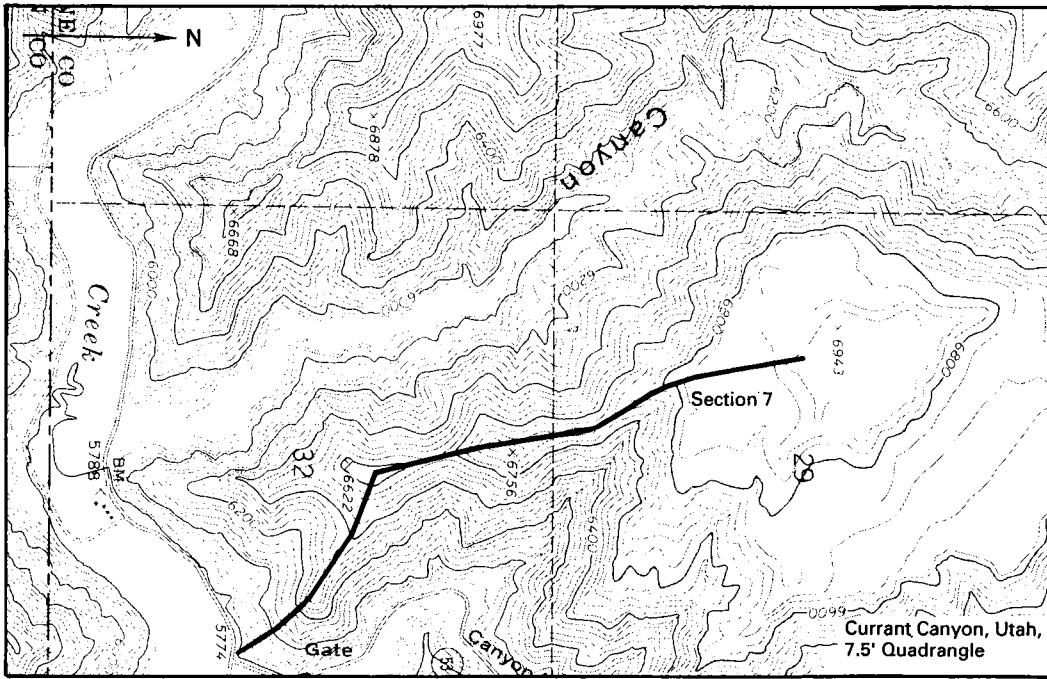
<sup>4</sup> Base of section 11 is 30 m above base of carbonate marker unit.

B. Locations of measured stratigraphic sections

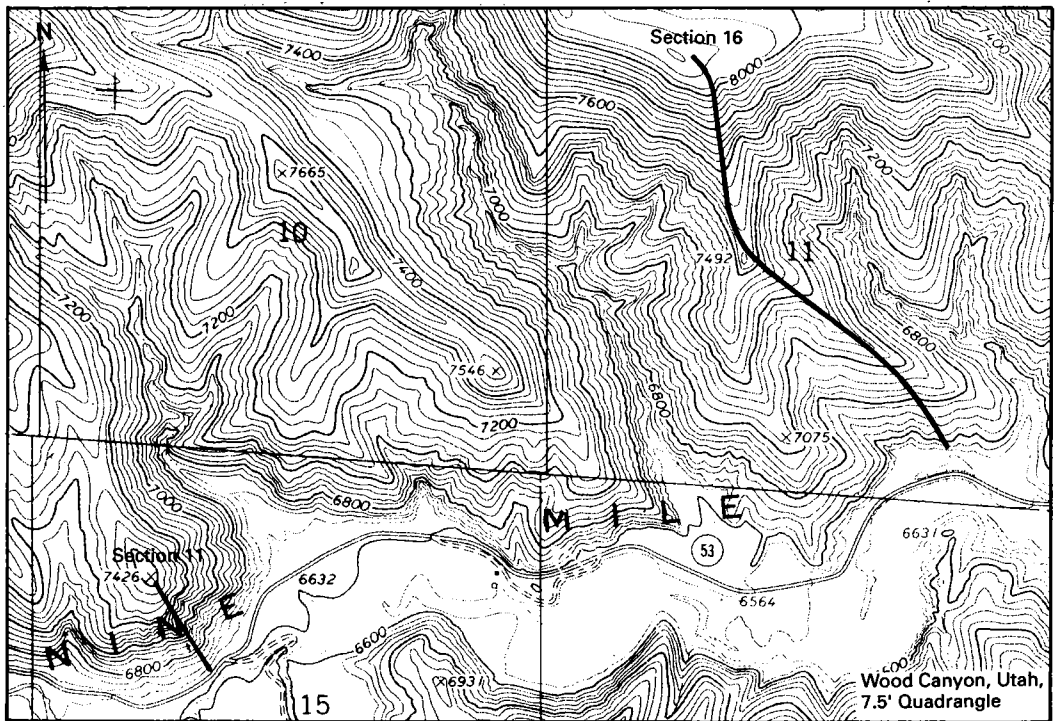
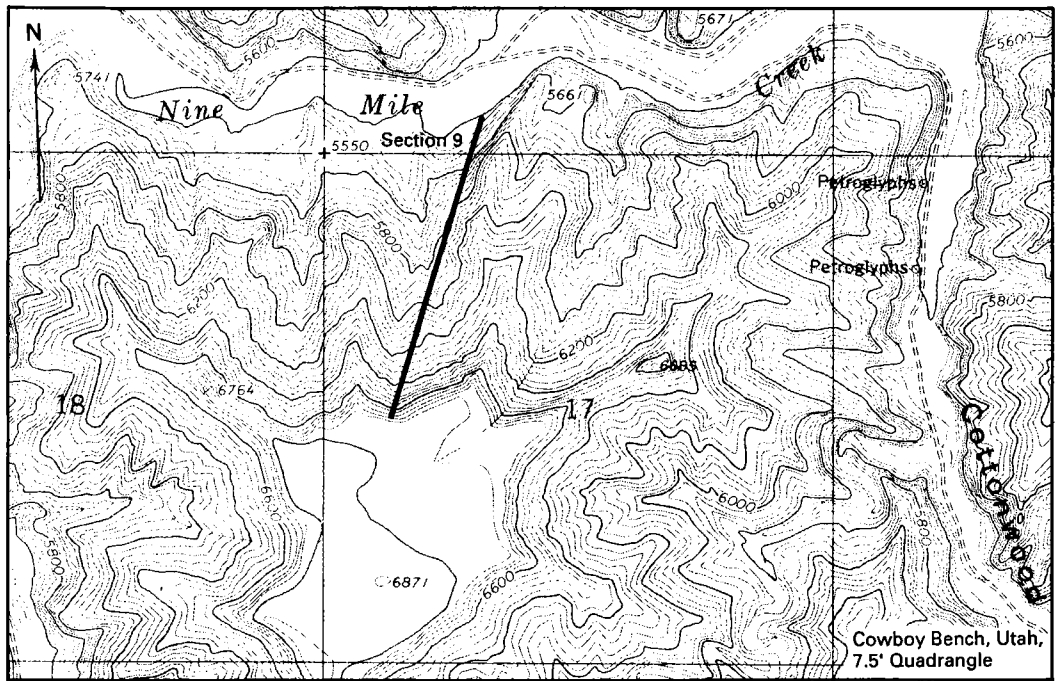




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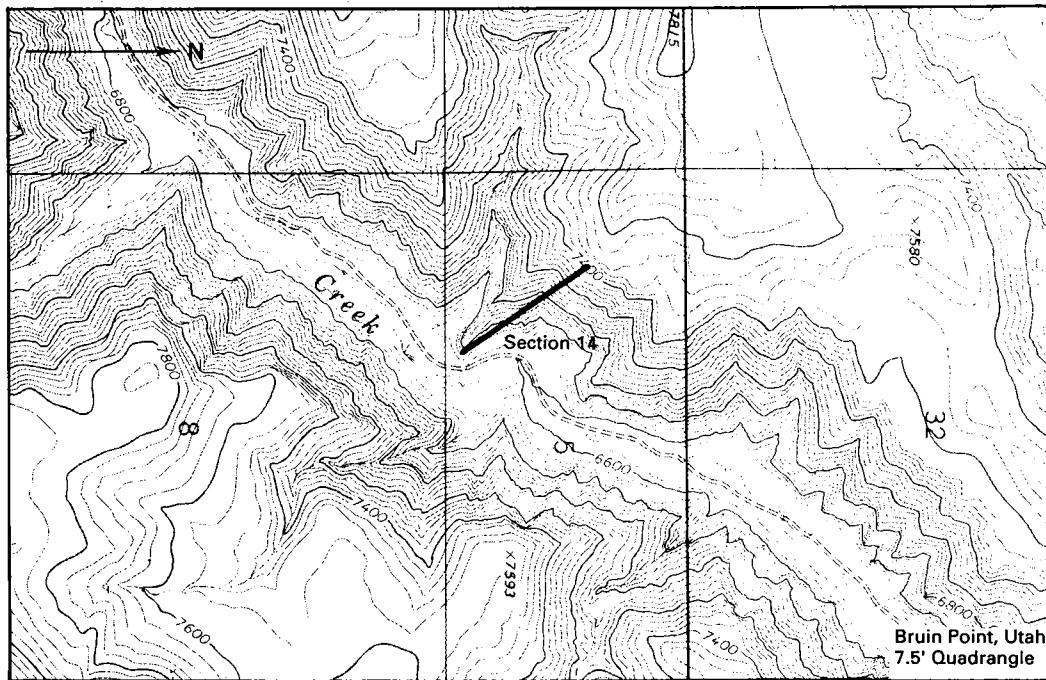
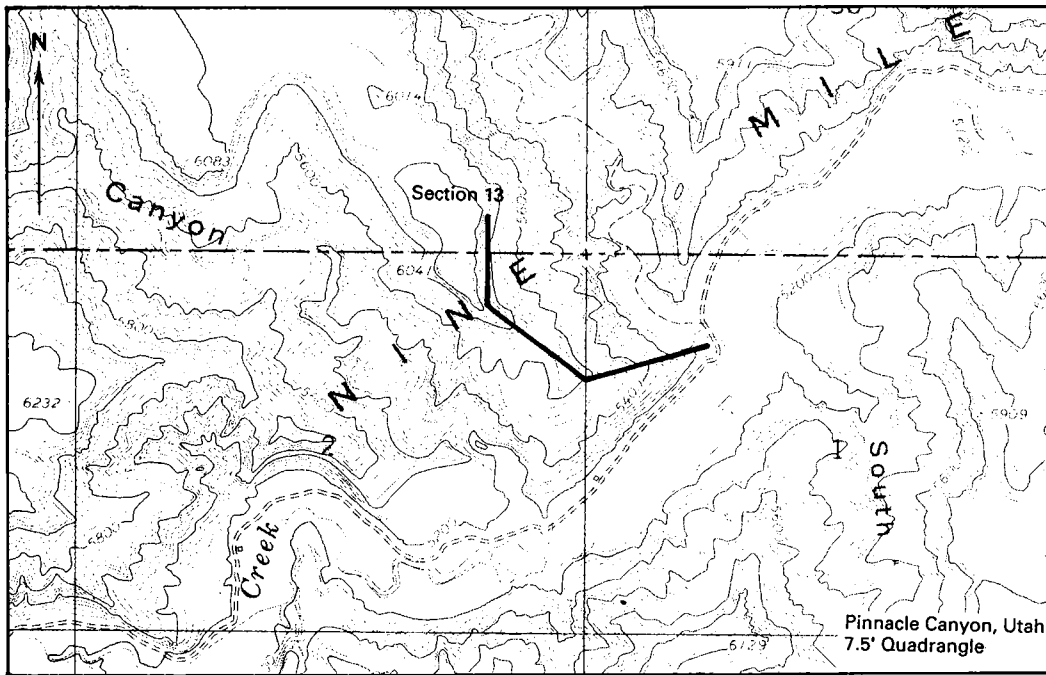
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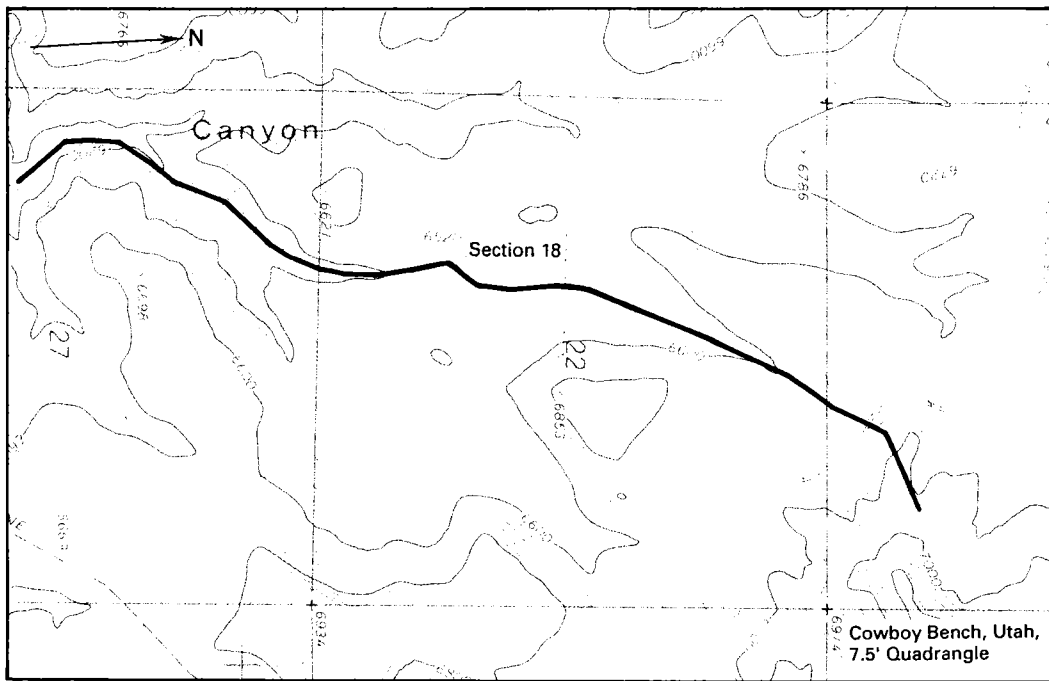
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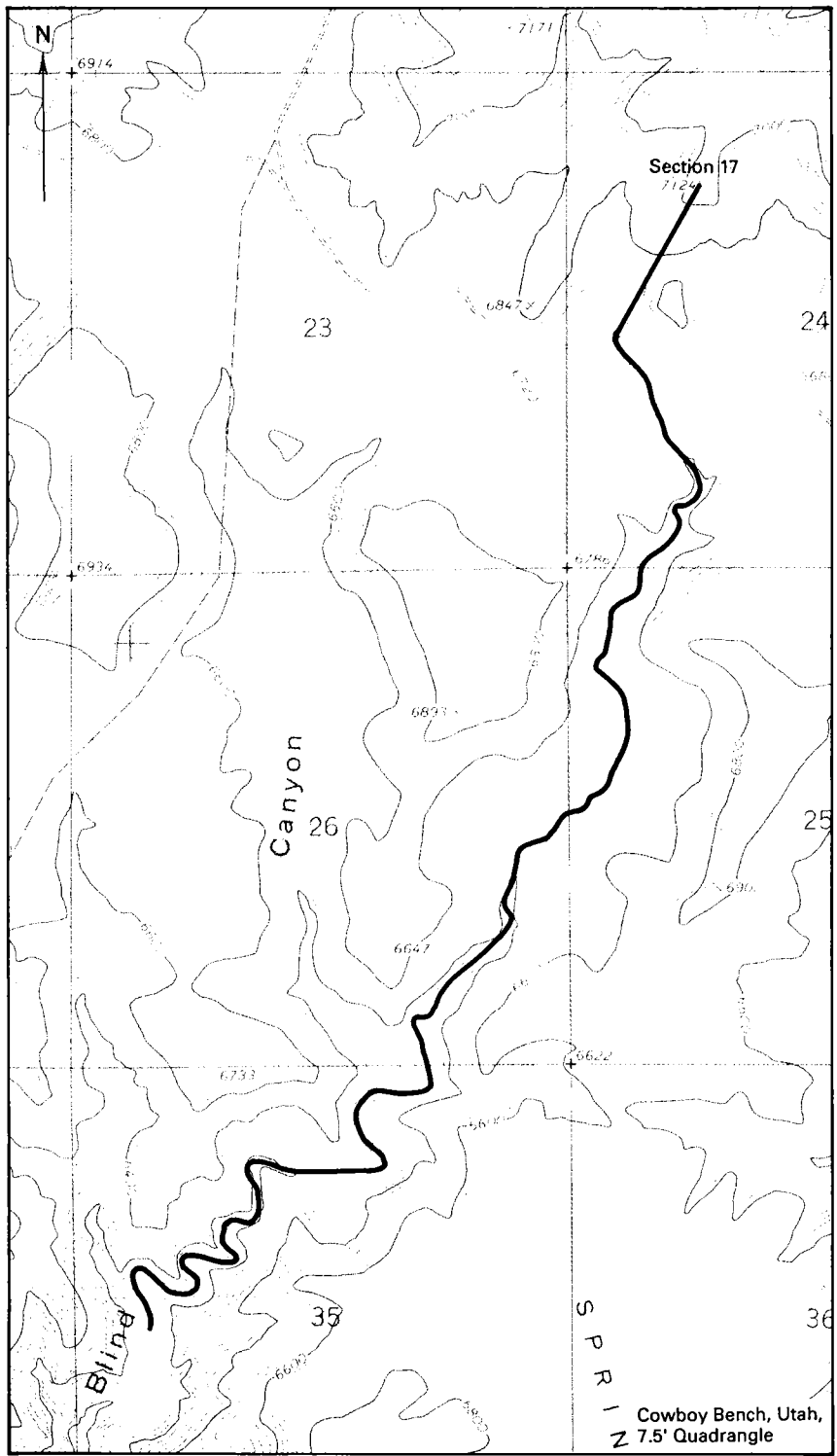
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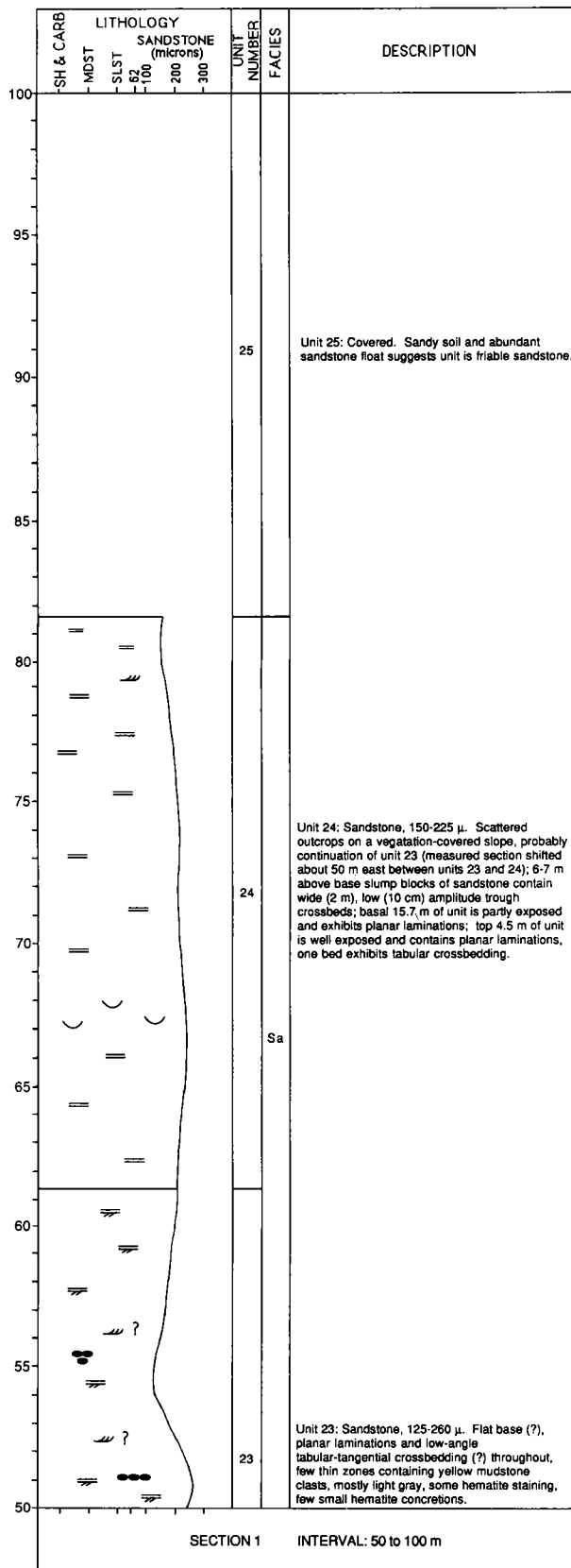
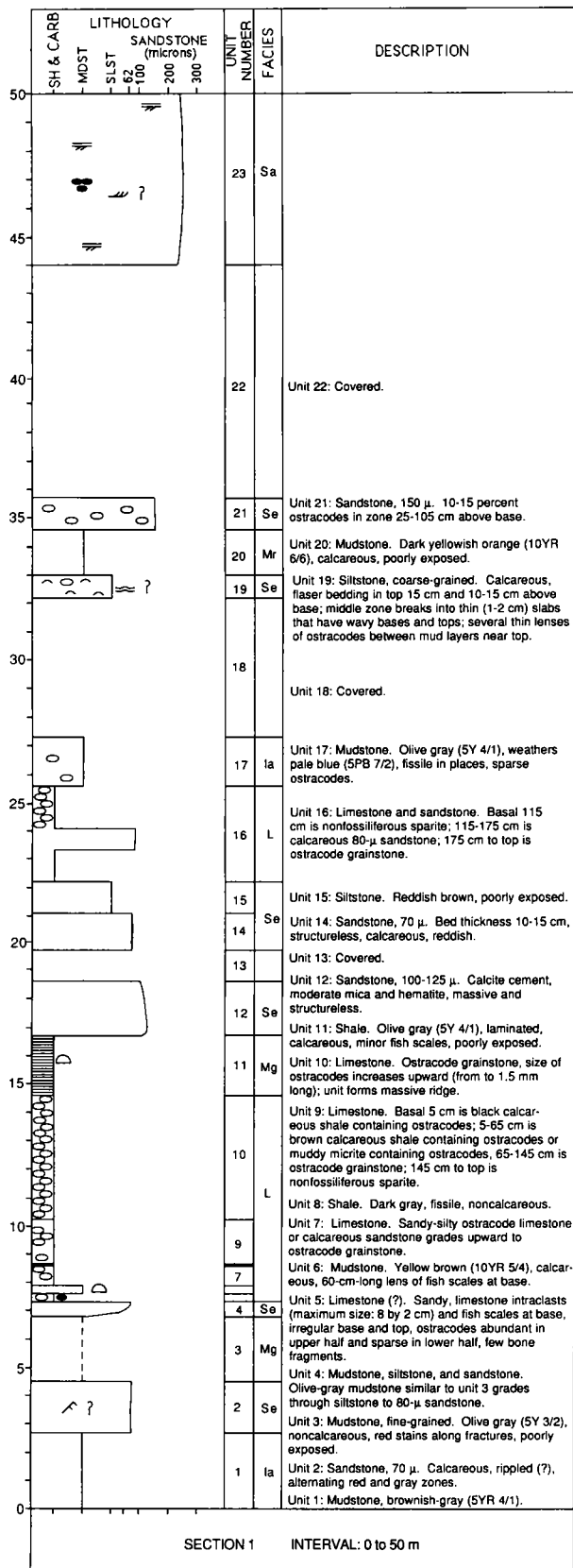
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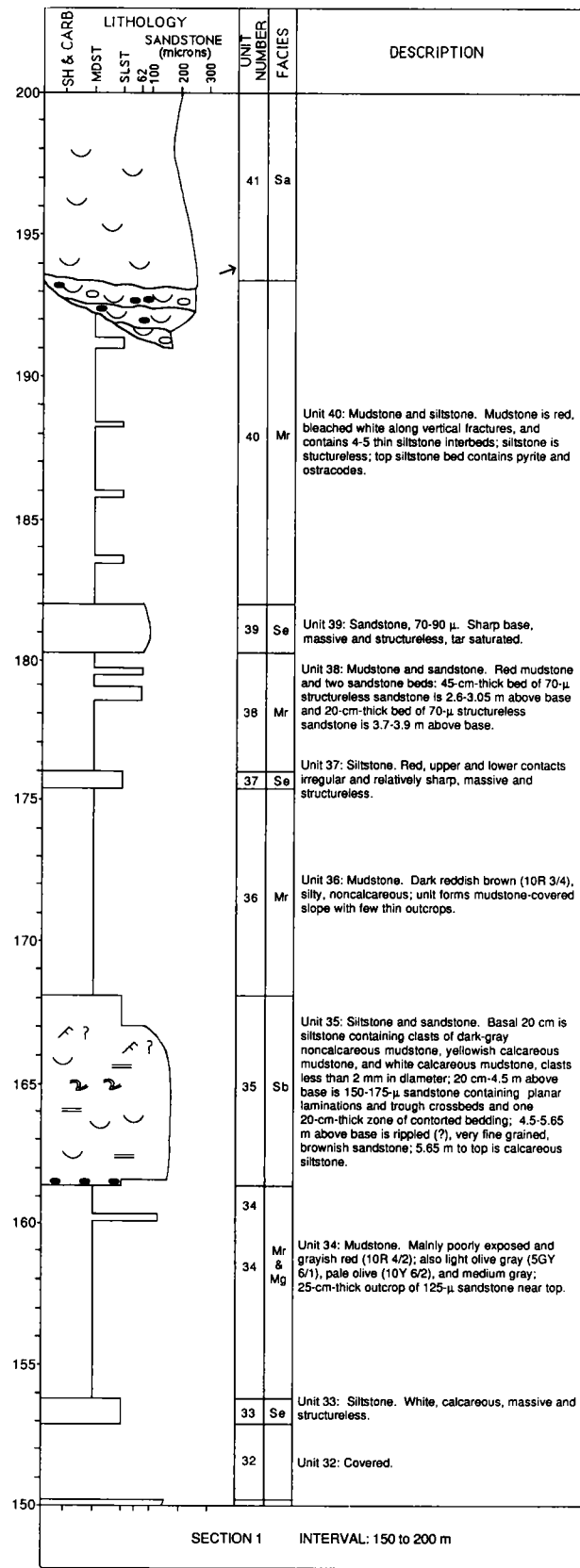
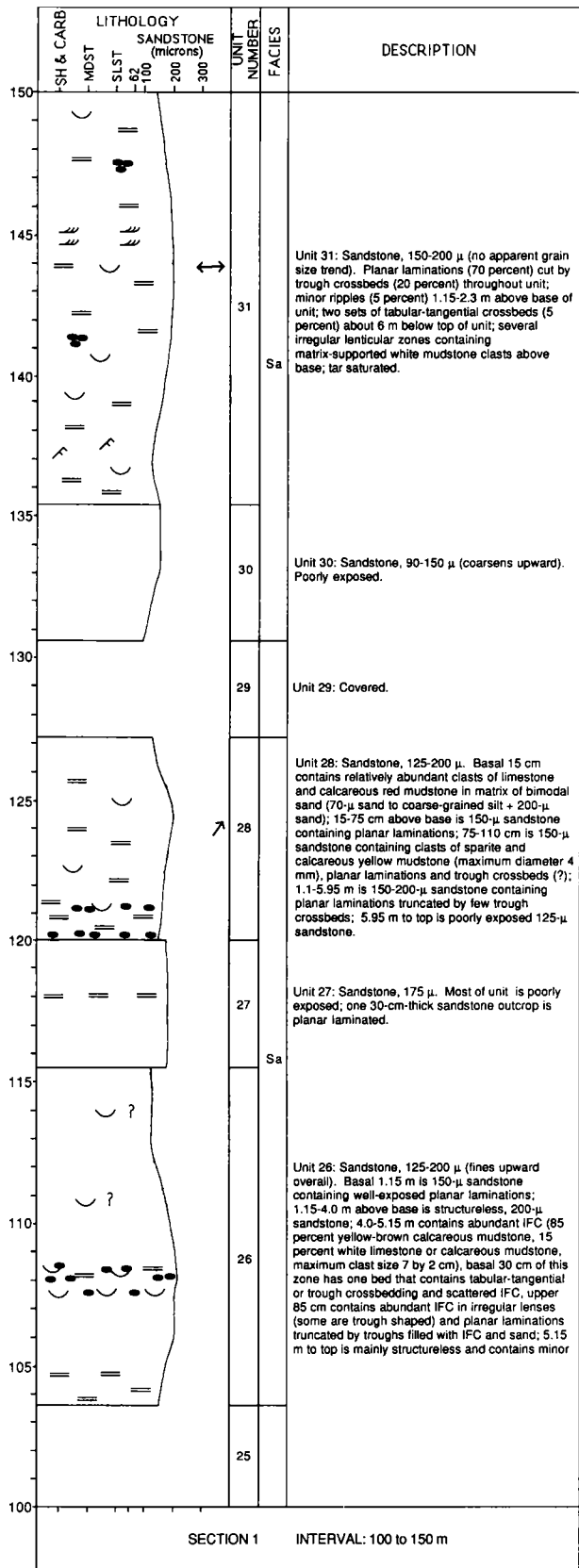
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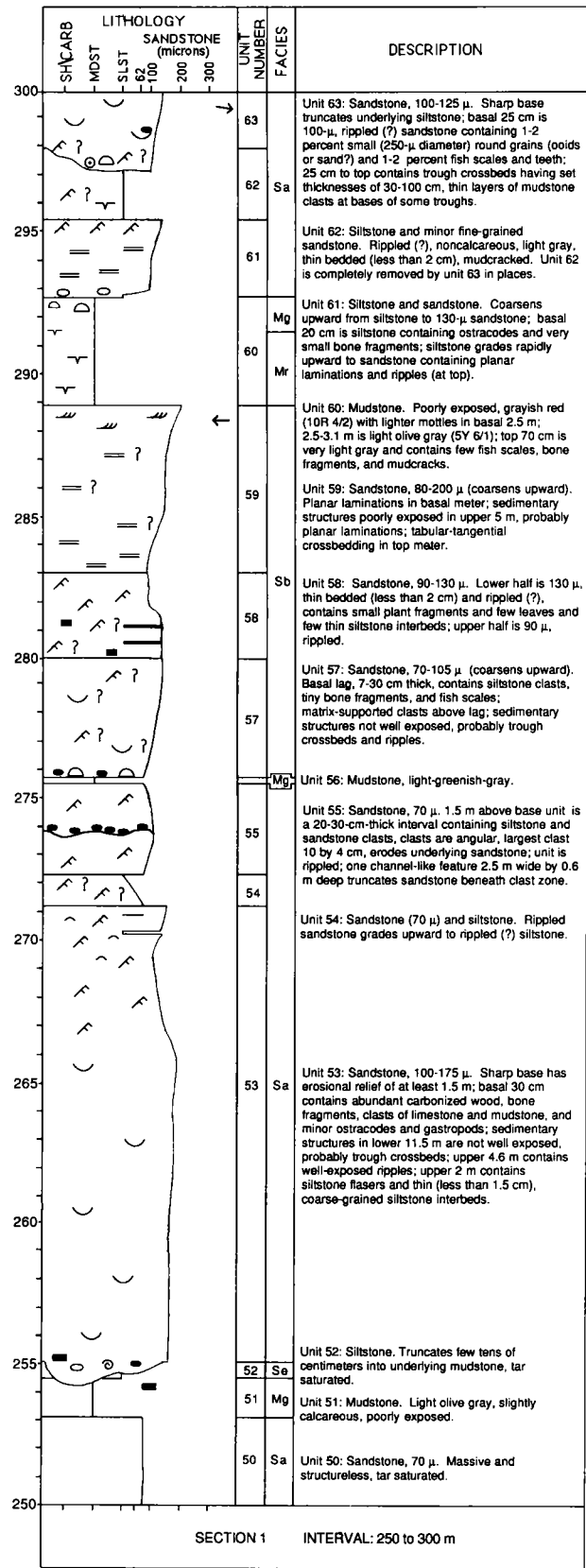
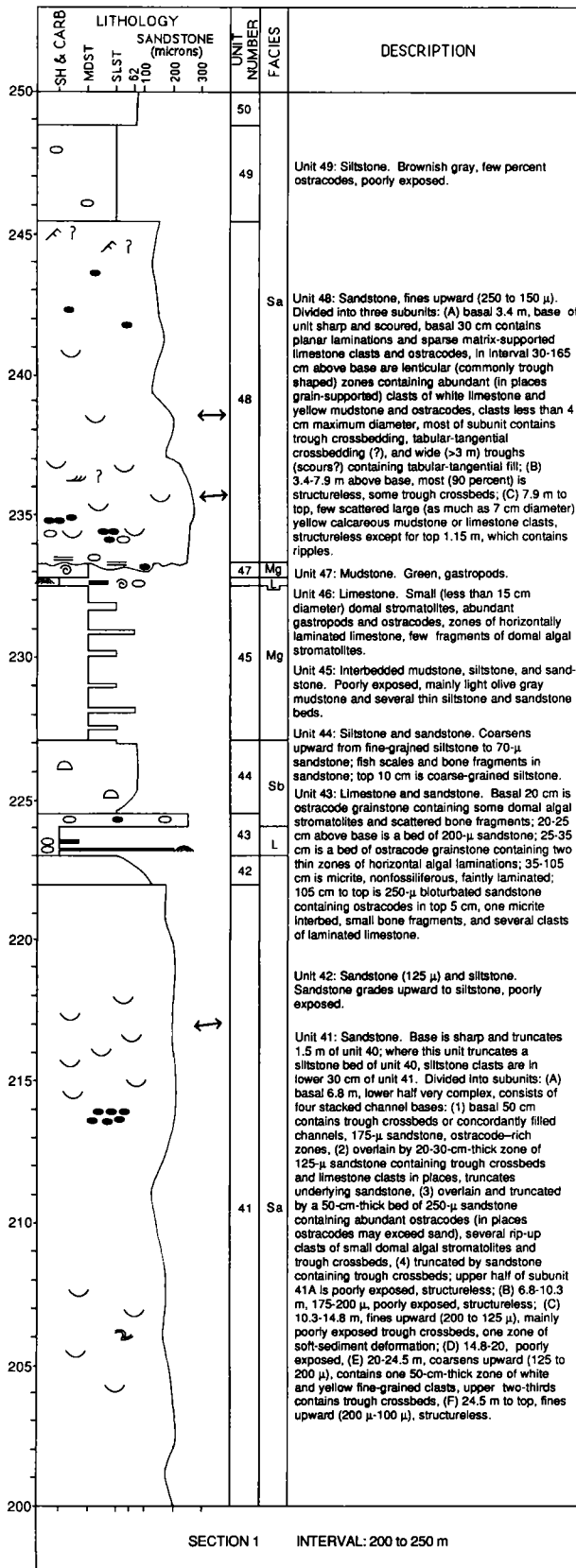


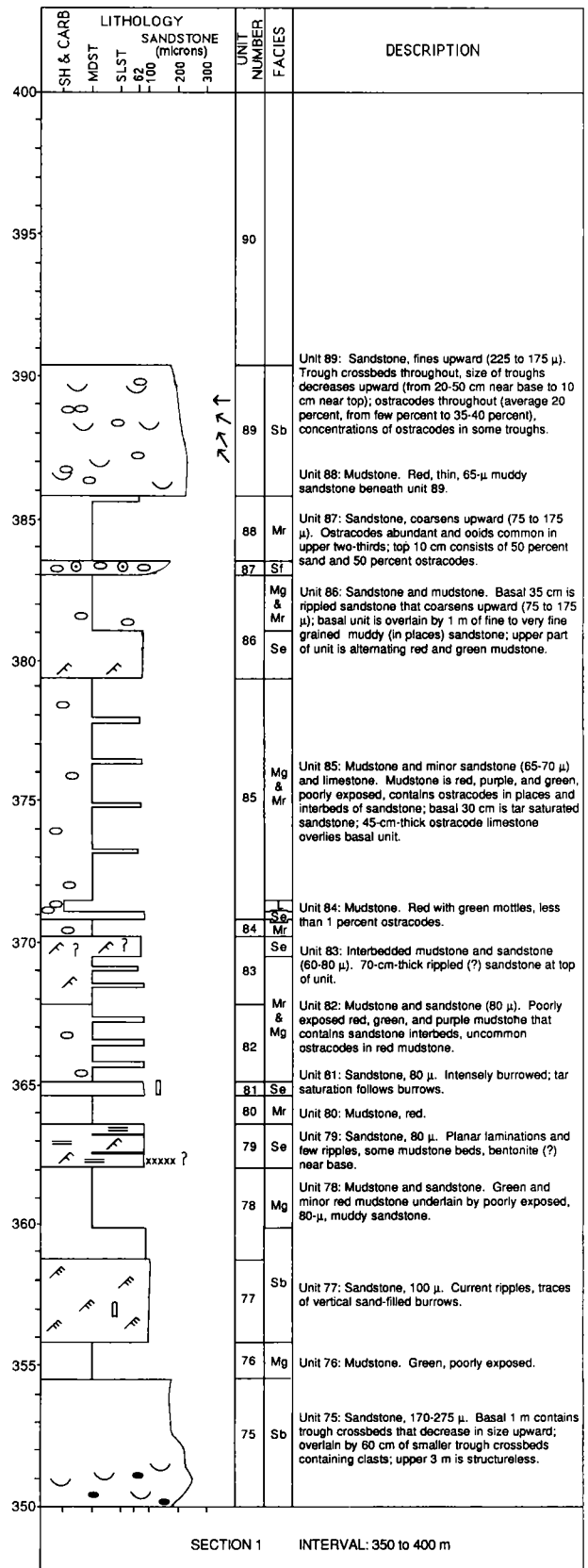
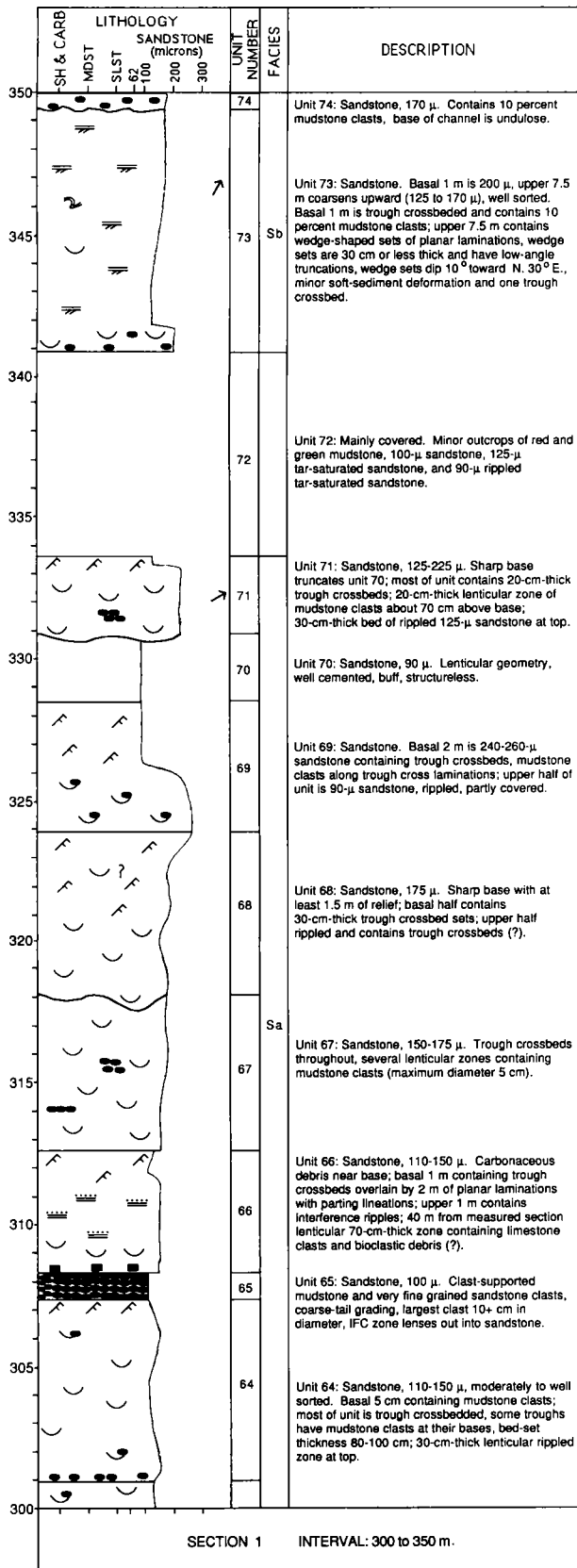


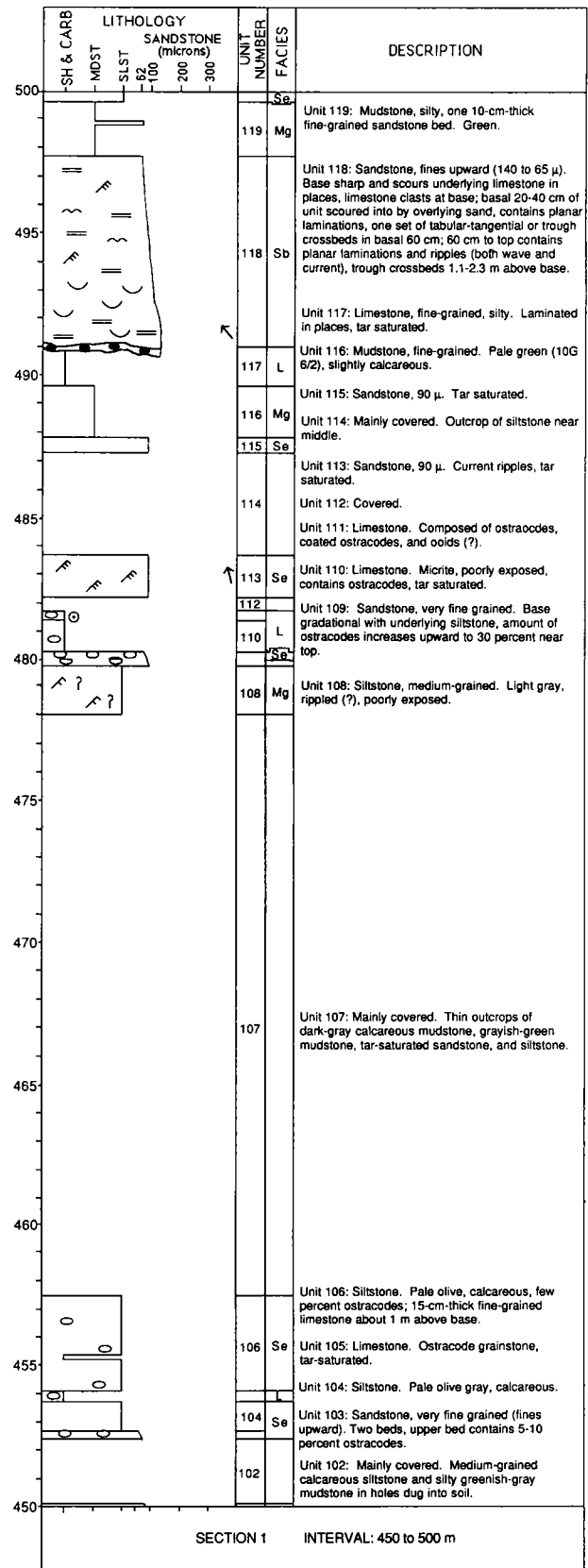
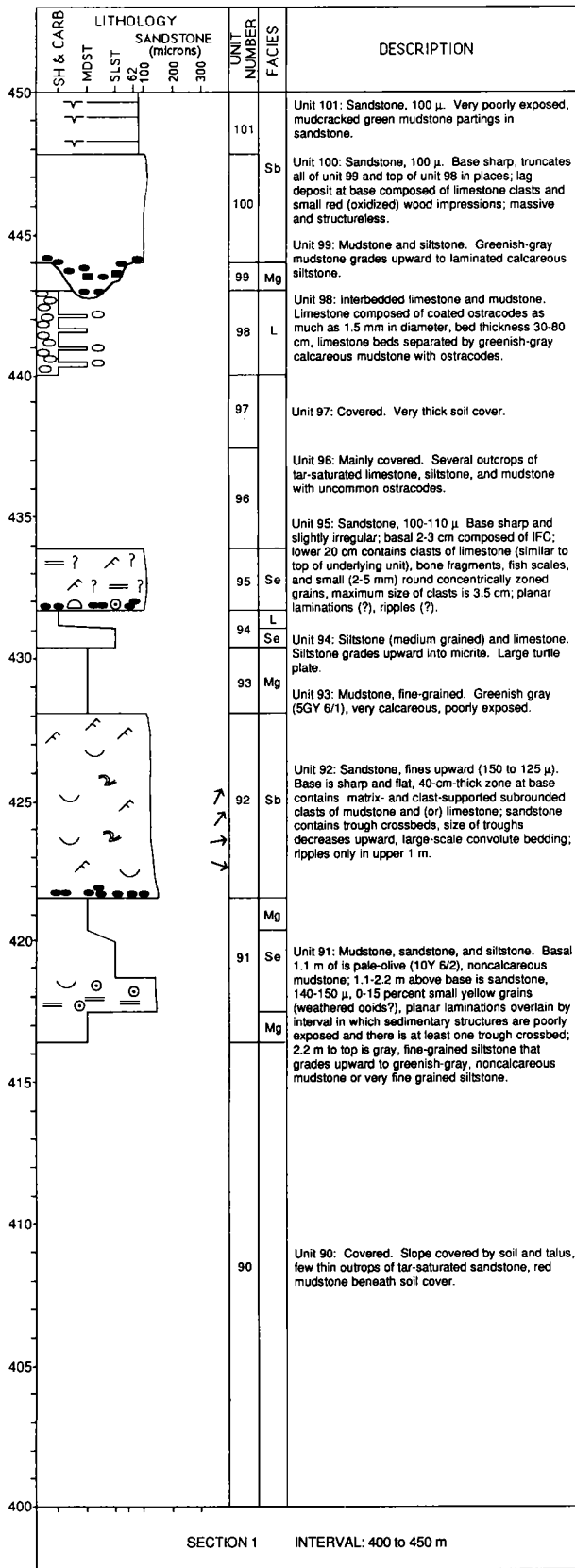
C. Measured stratigraphic sections

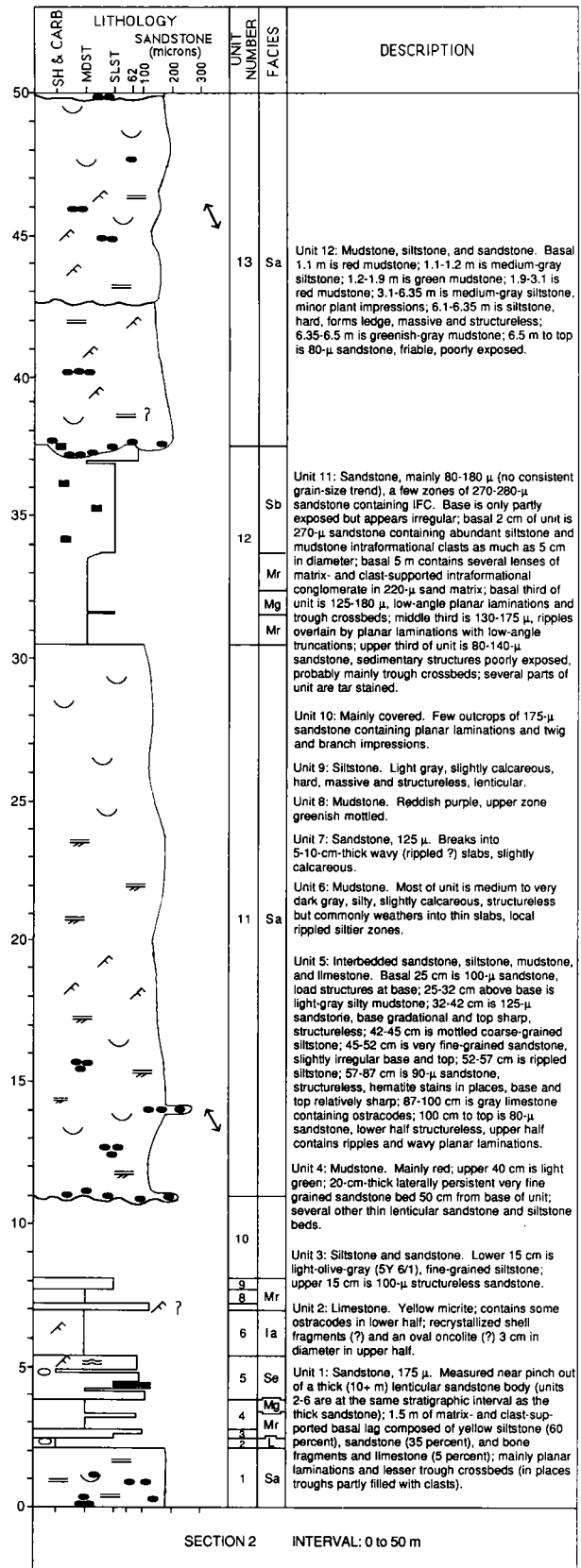
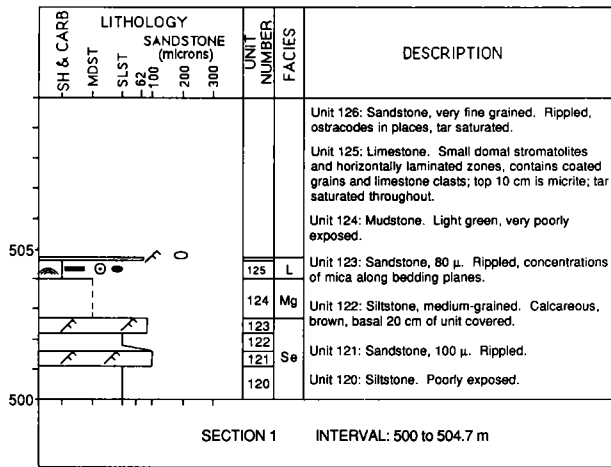


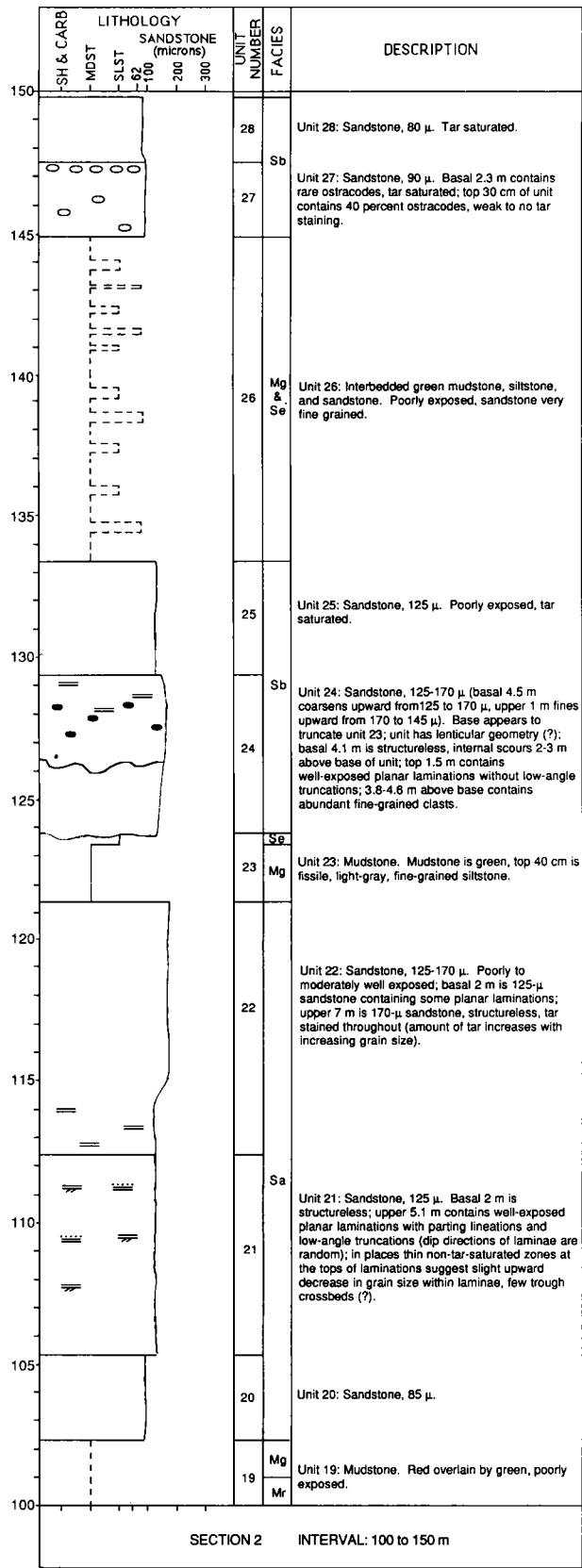
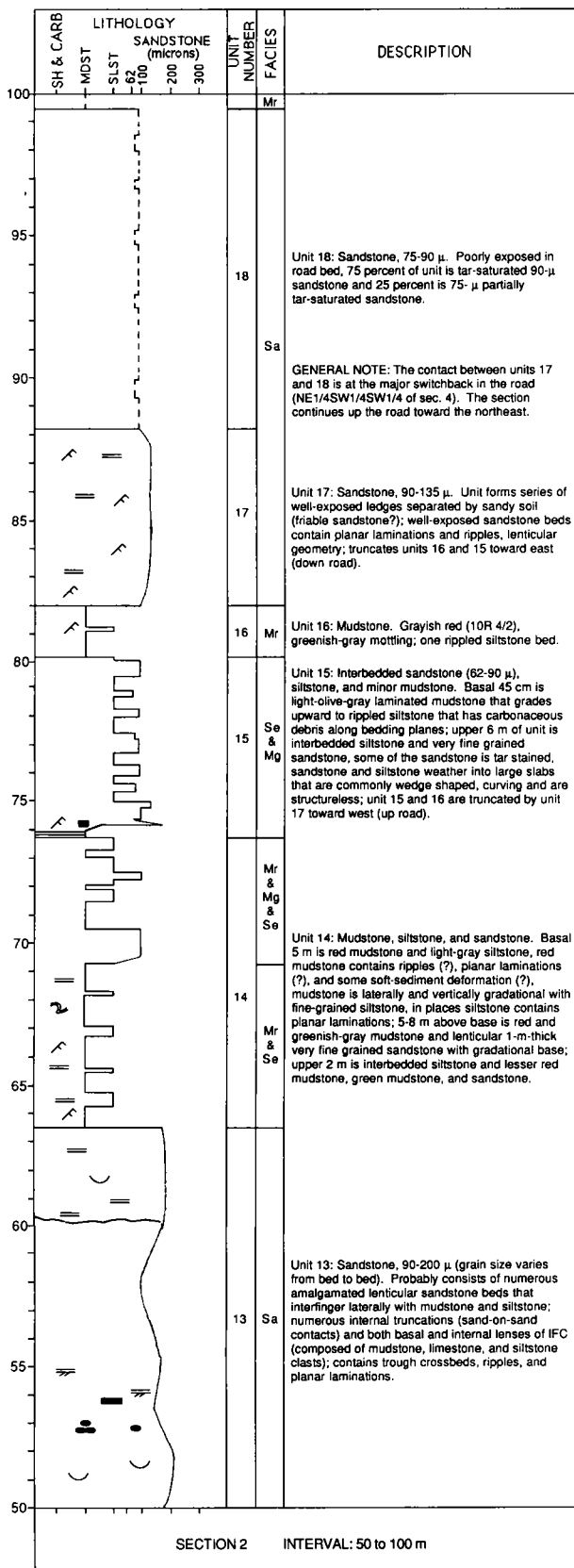




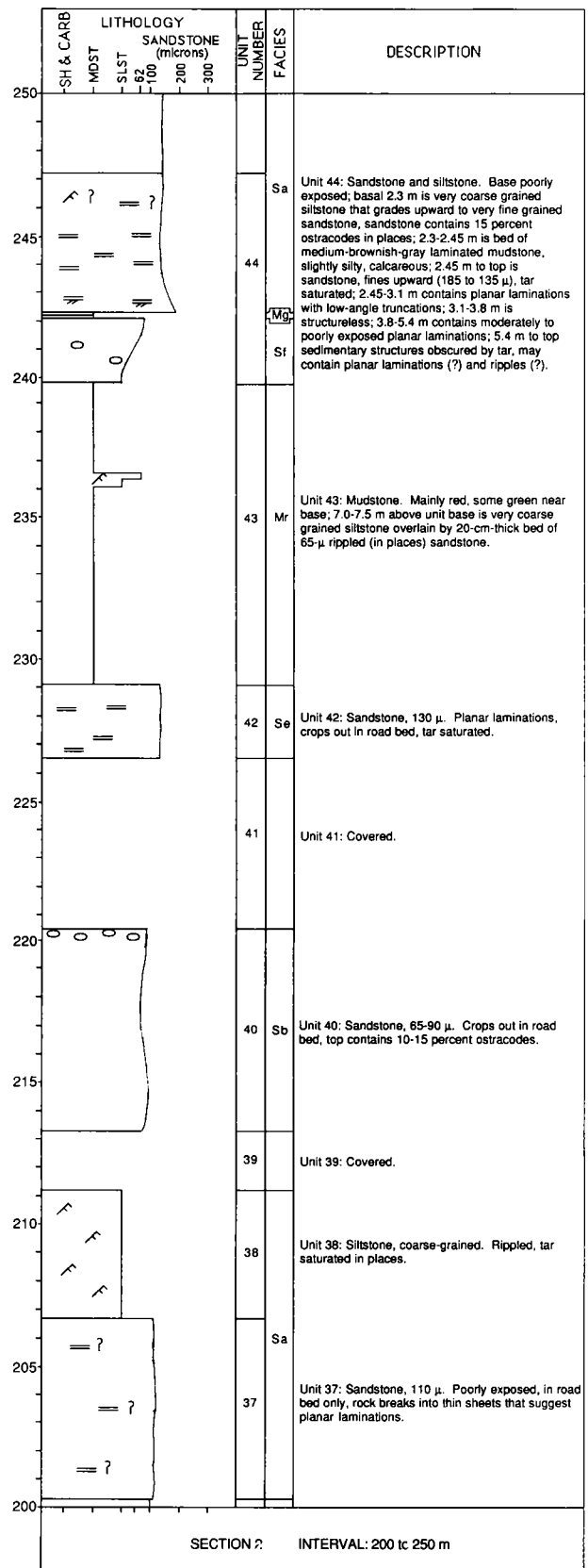
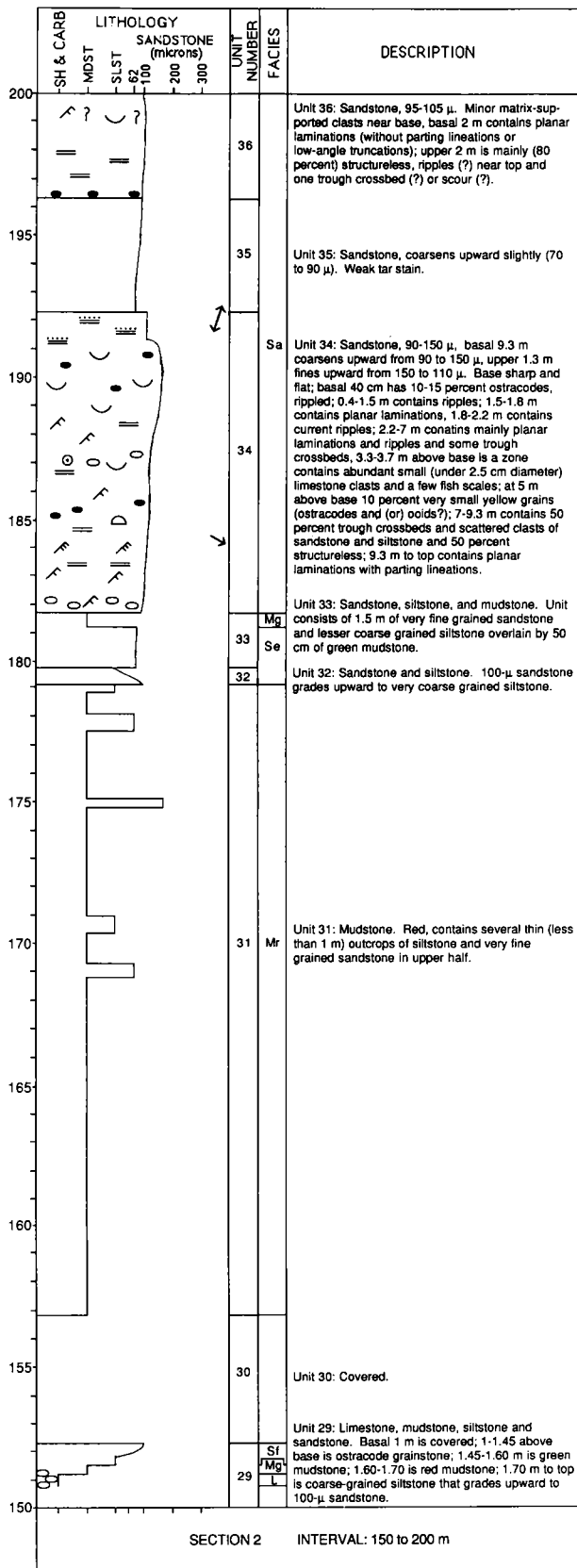


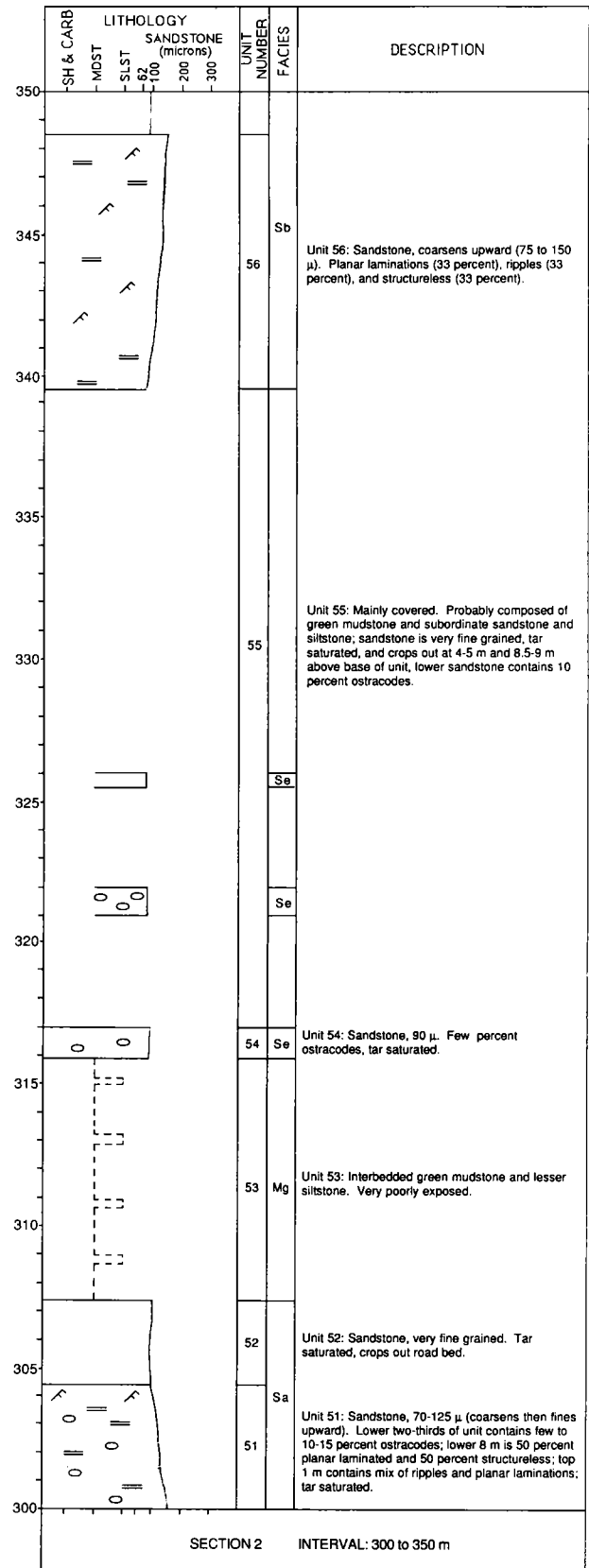
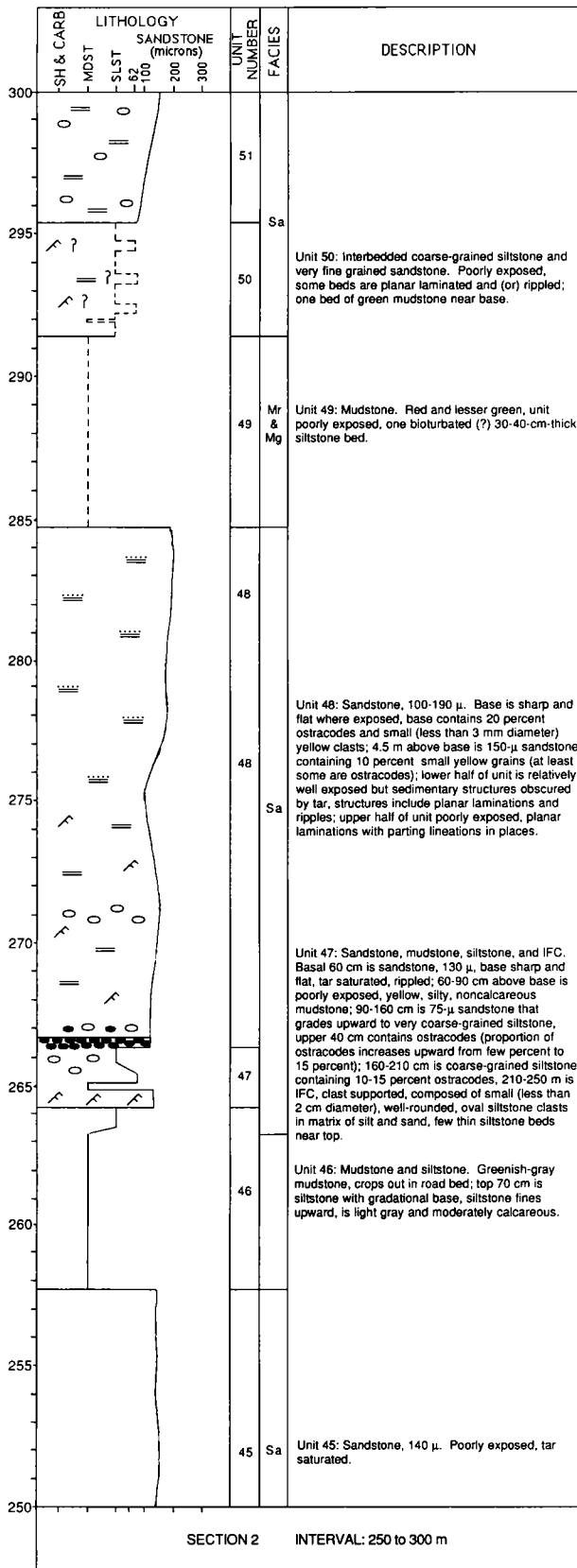


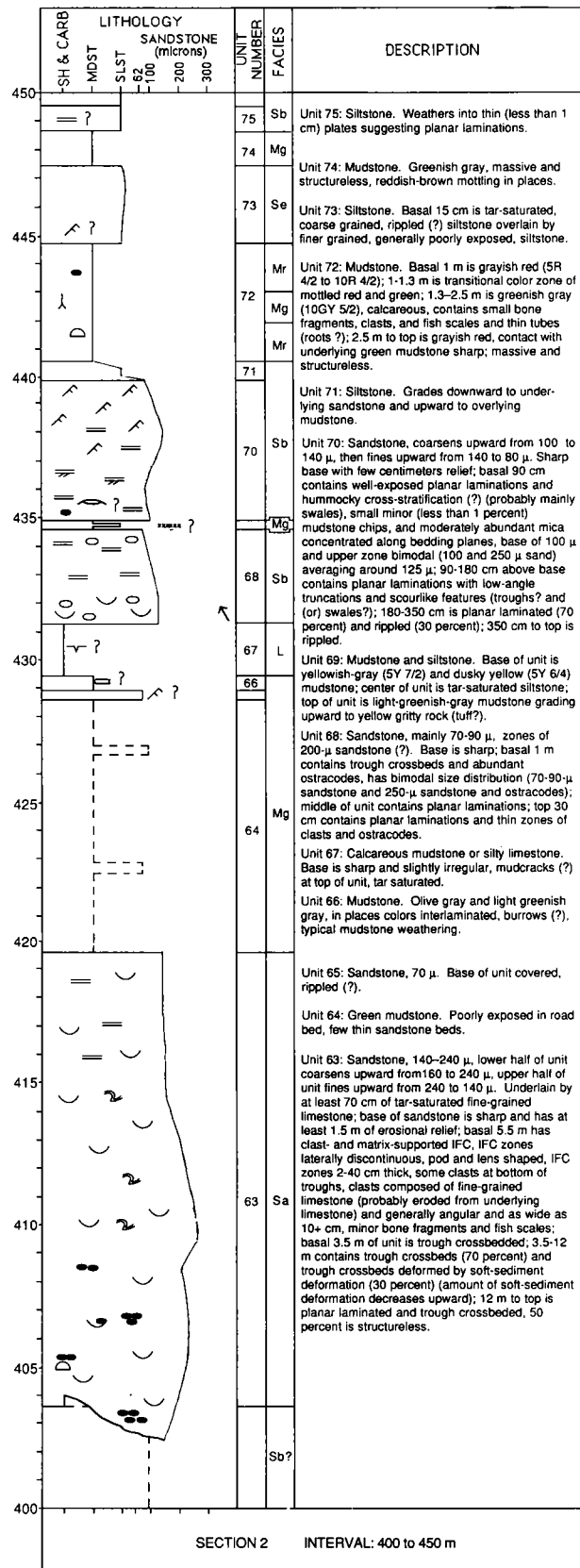
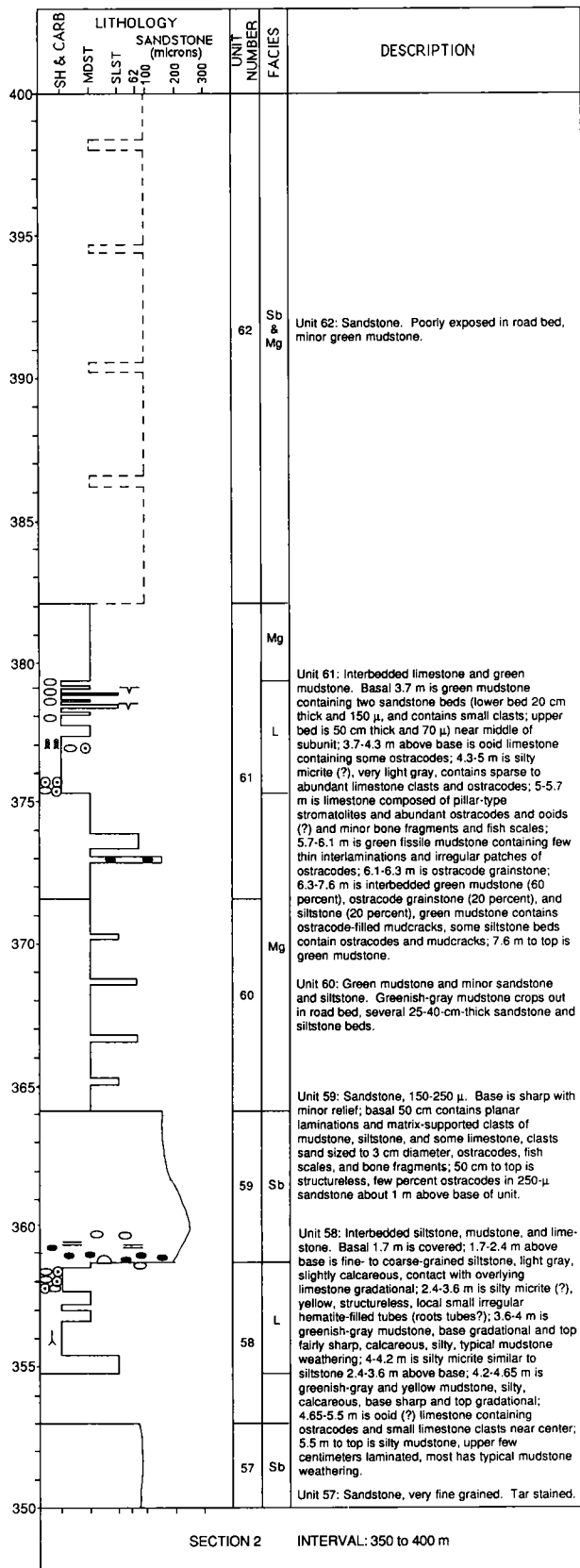


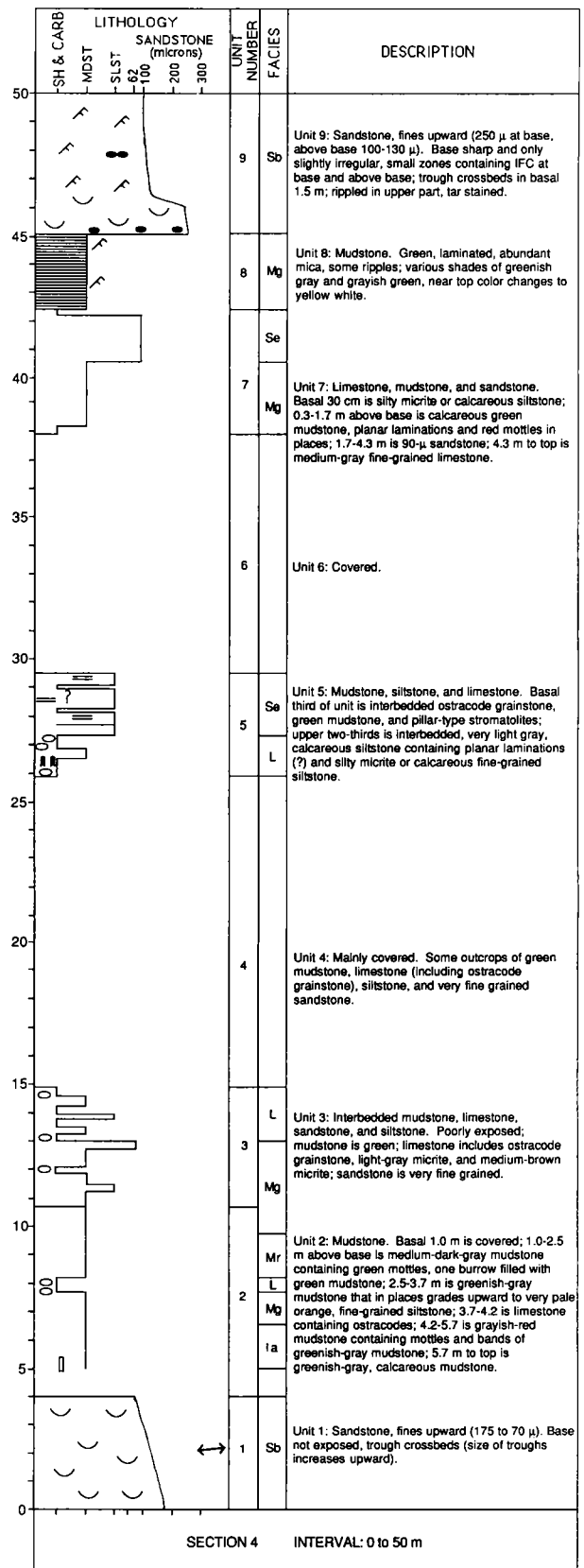
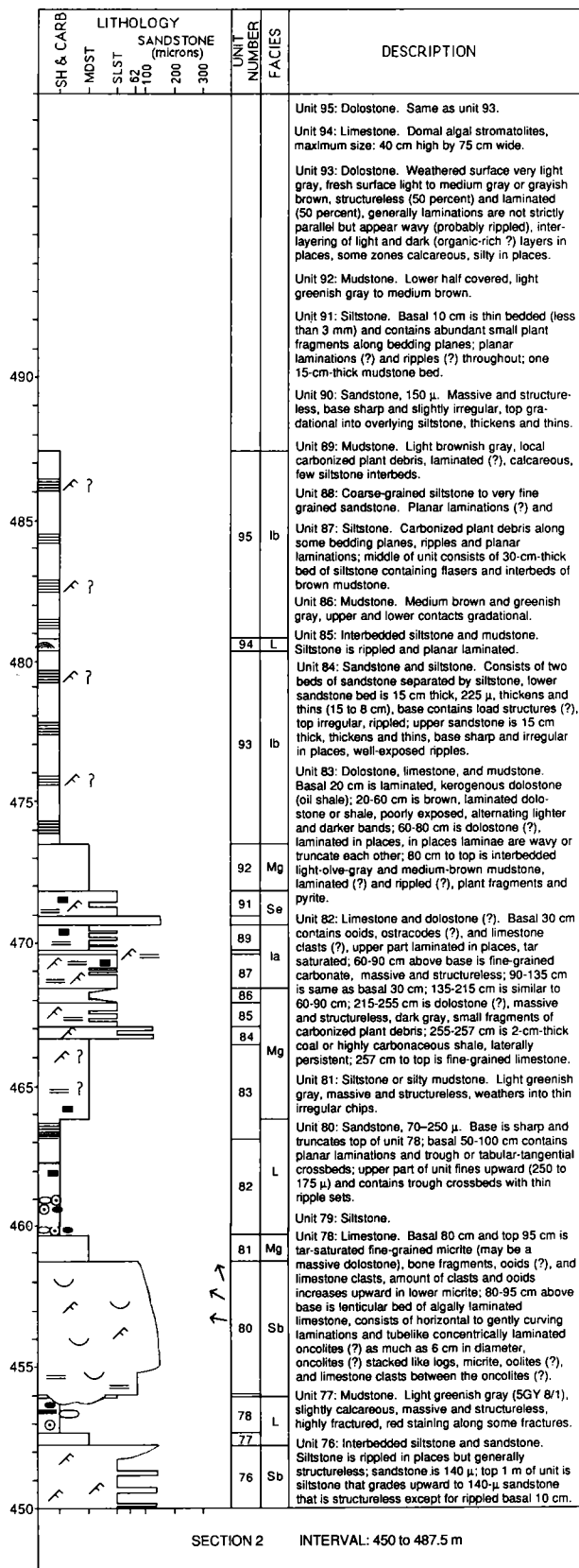


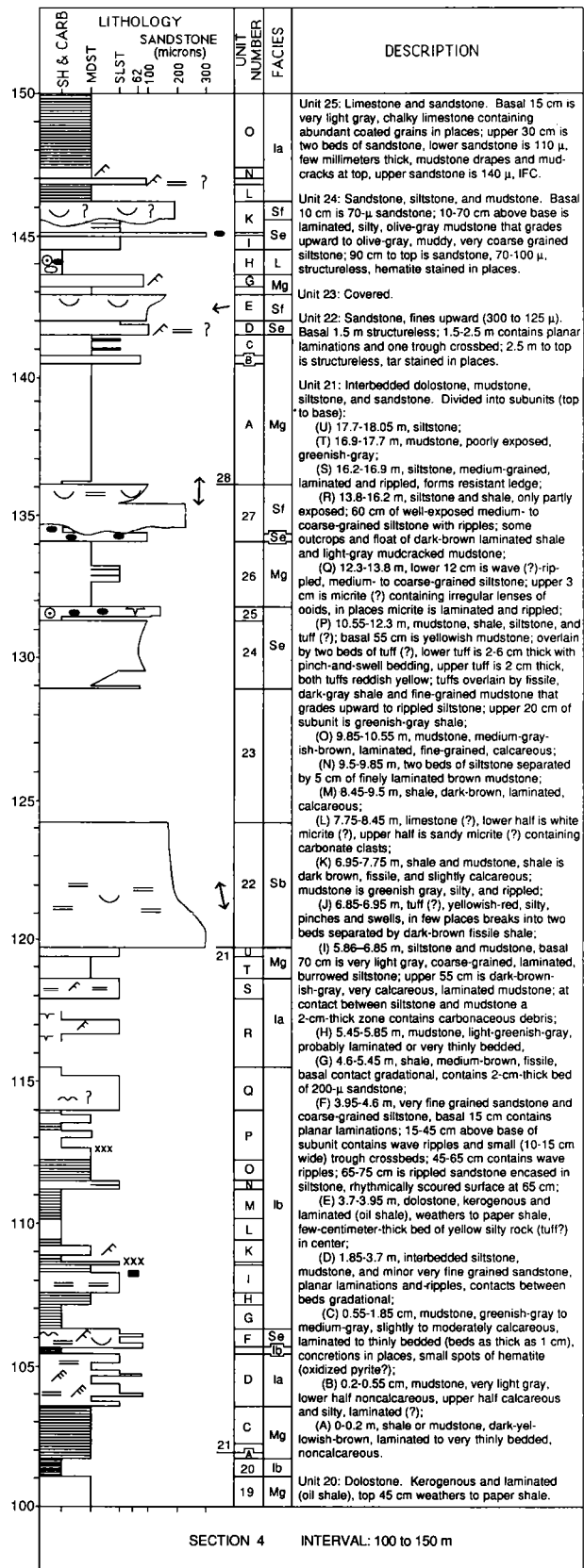
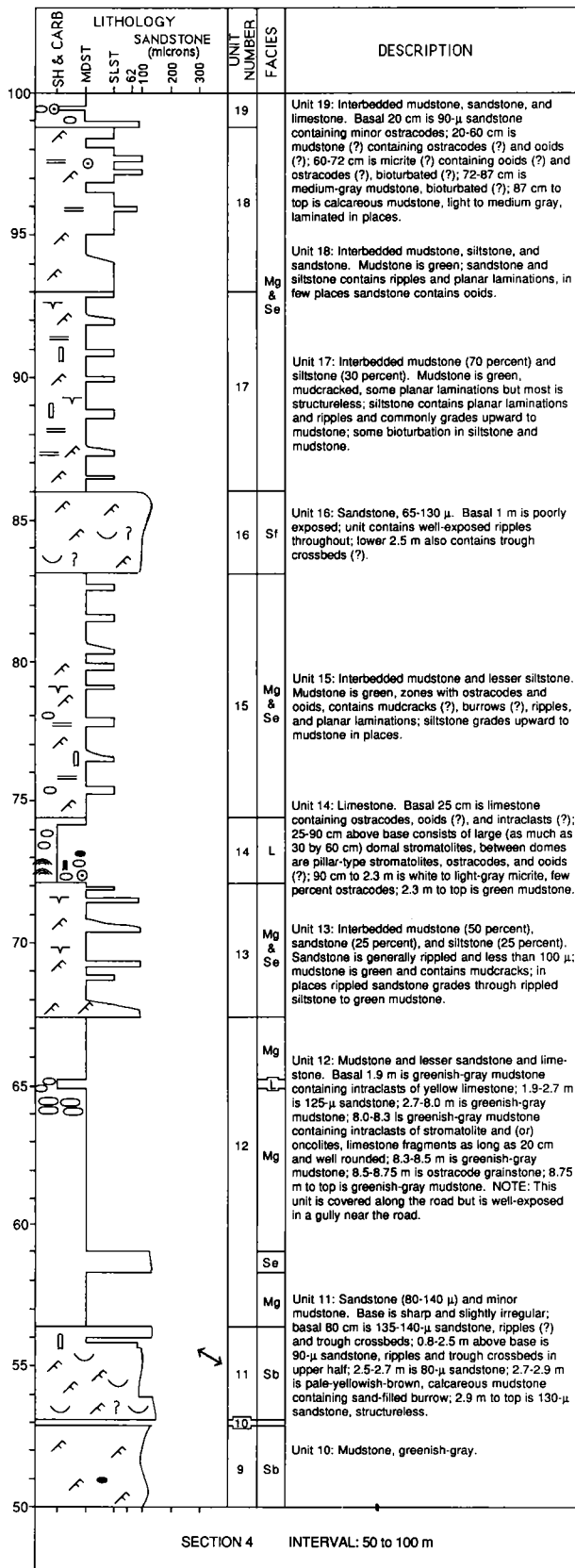


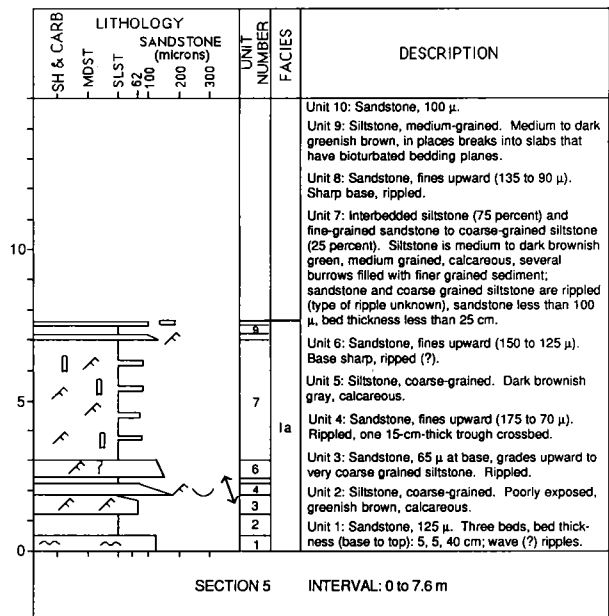
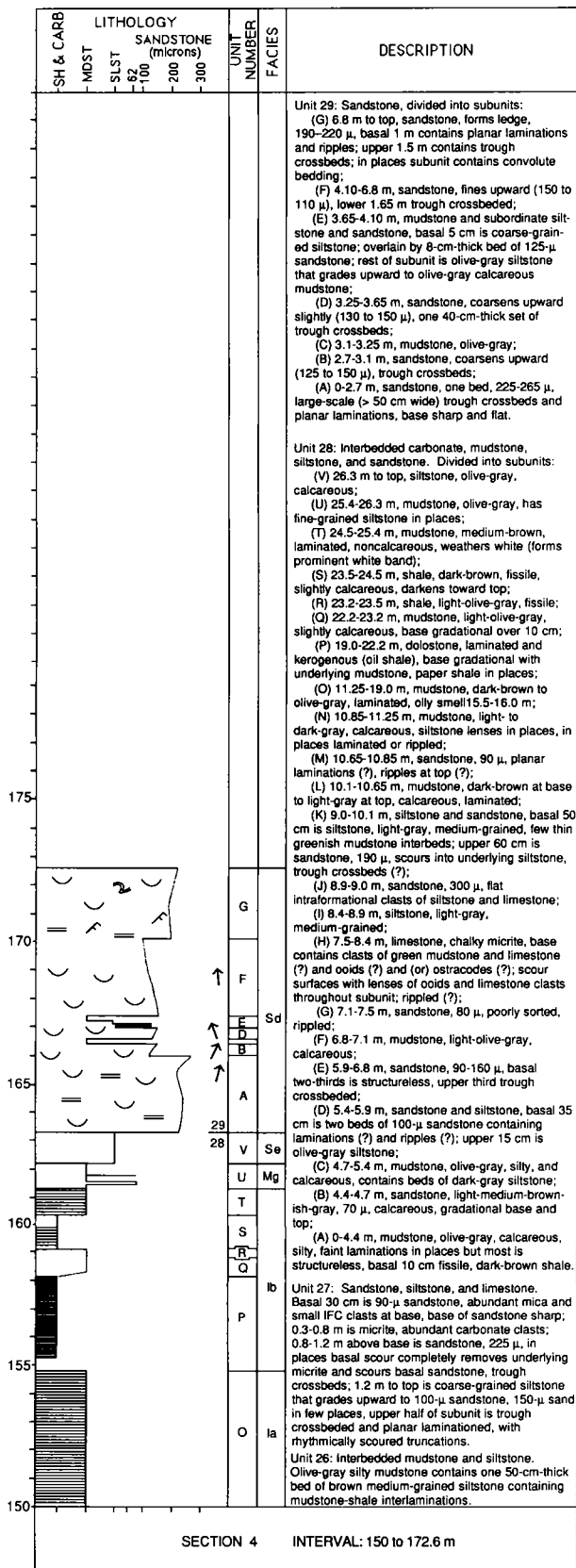


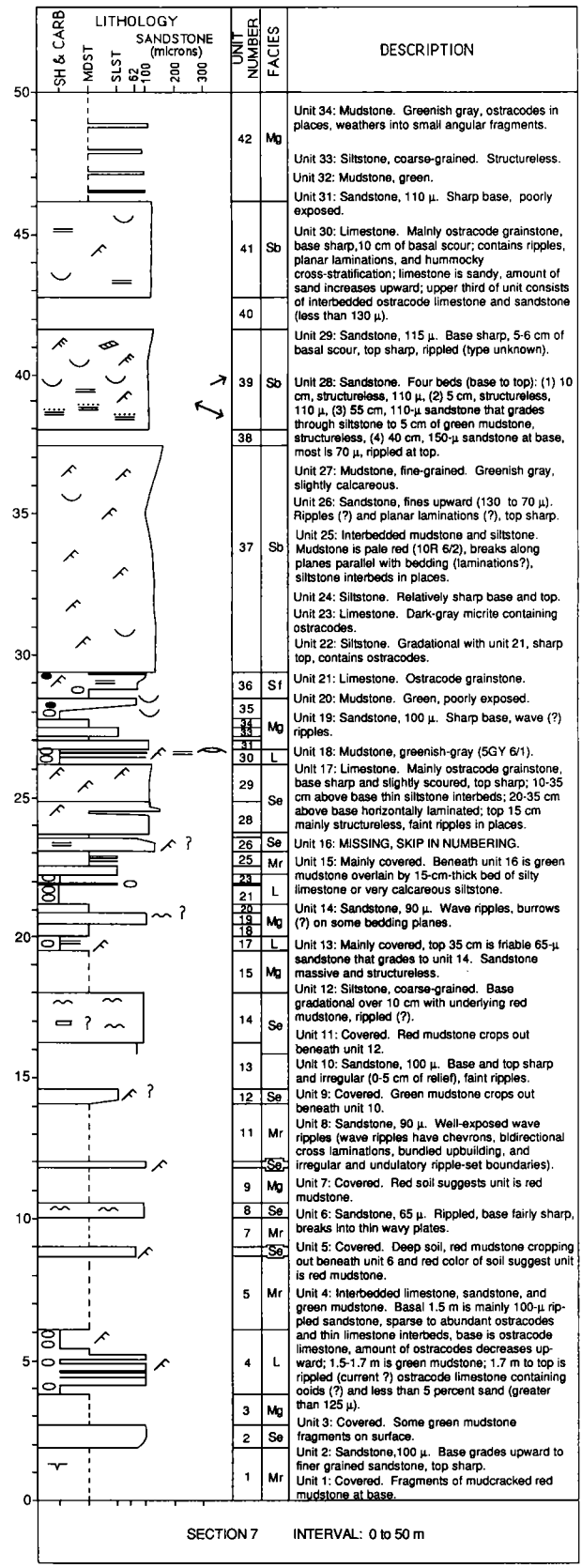
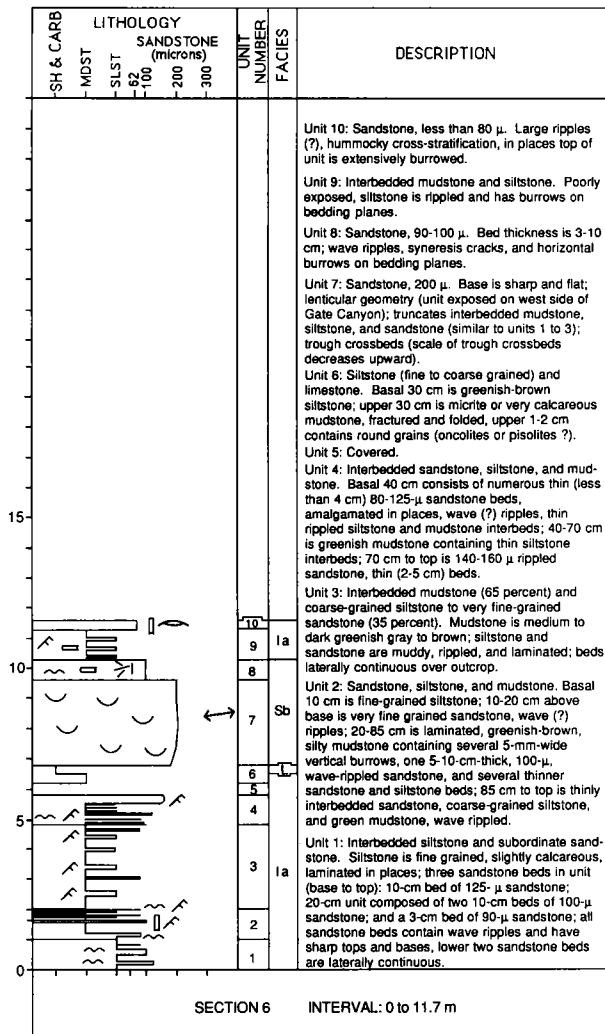


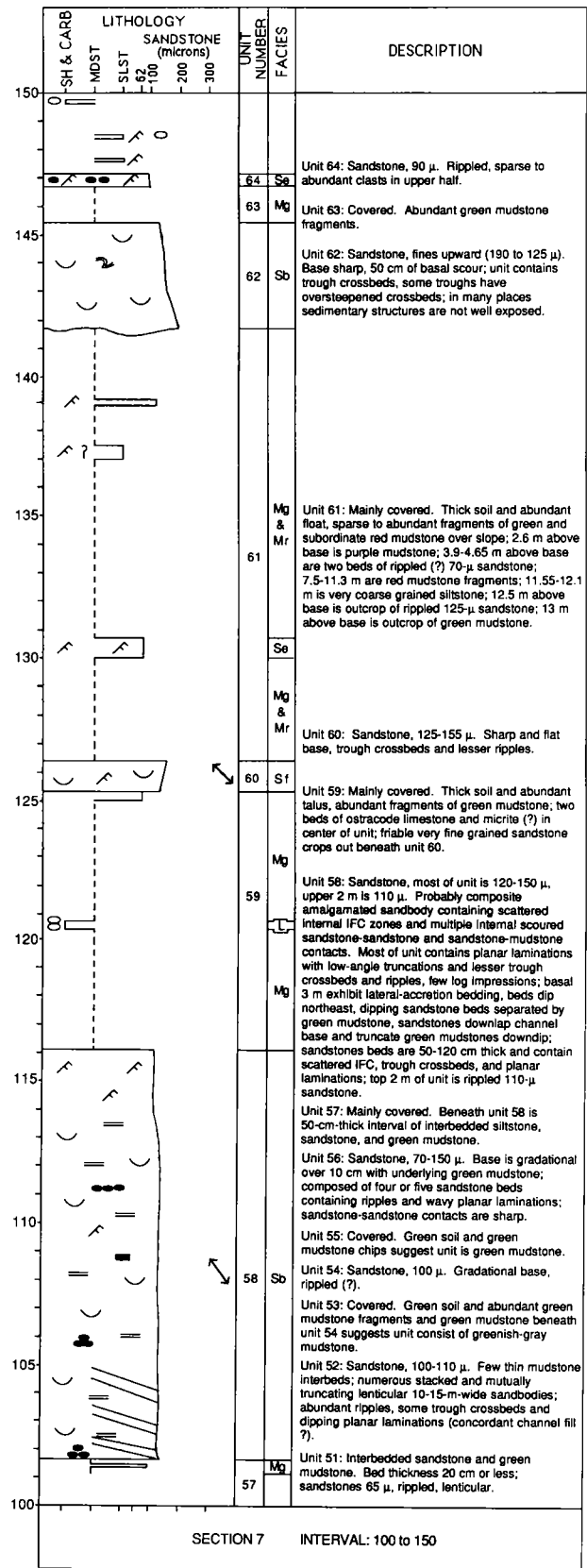
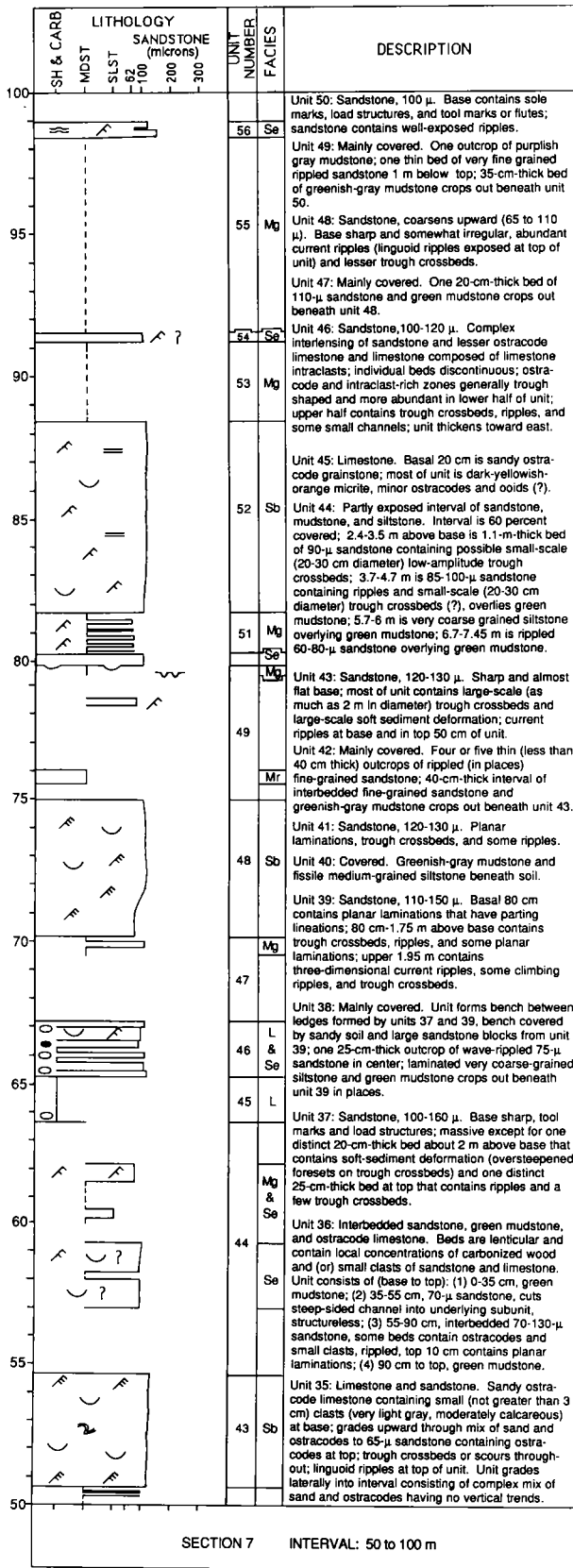




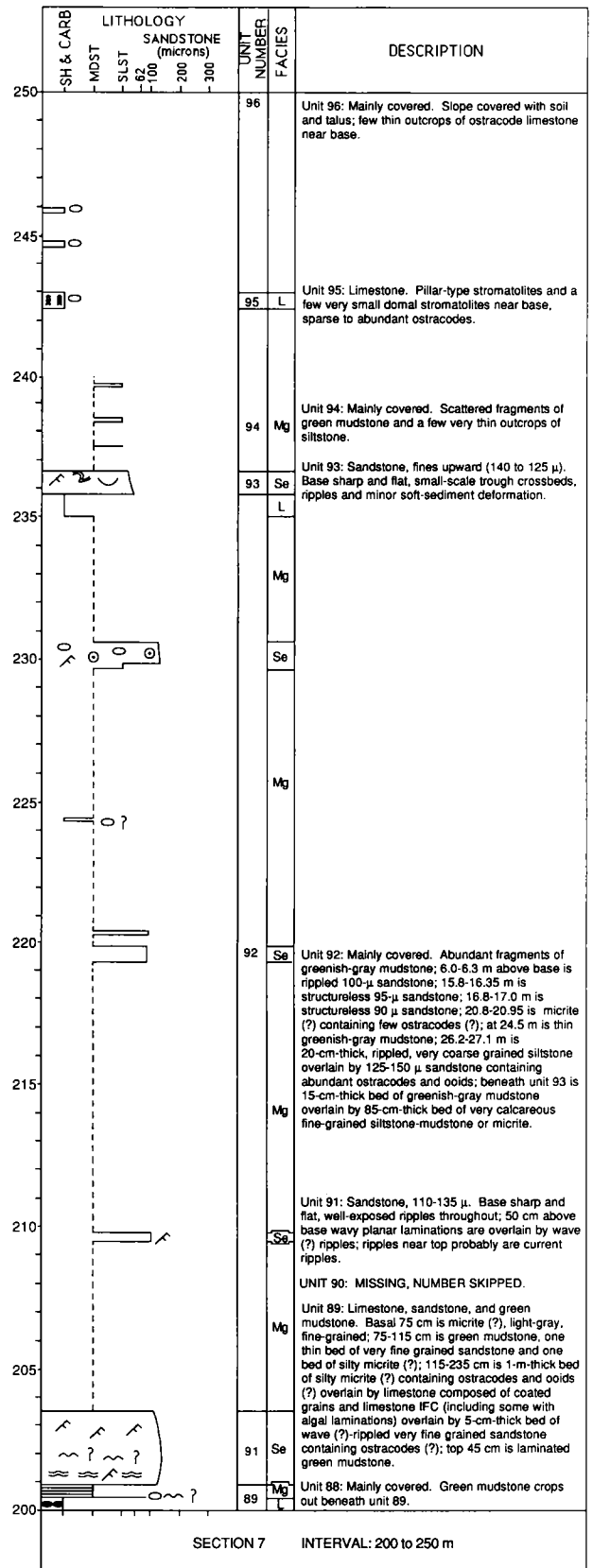
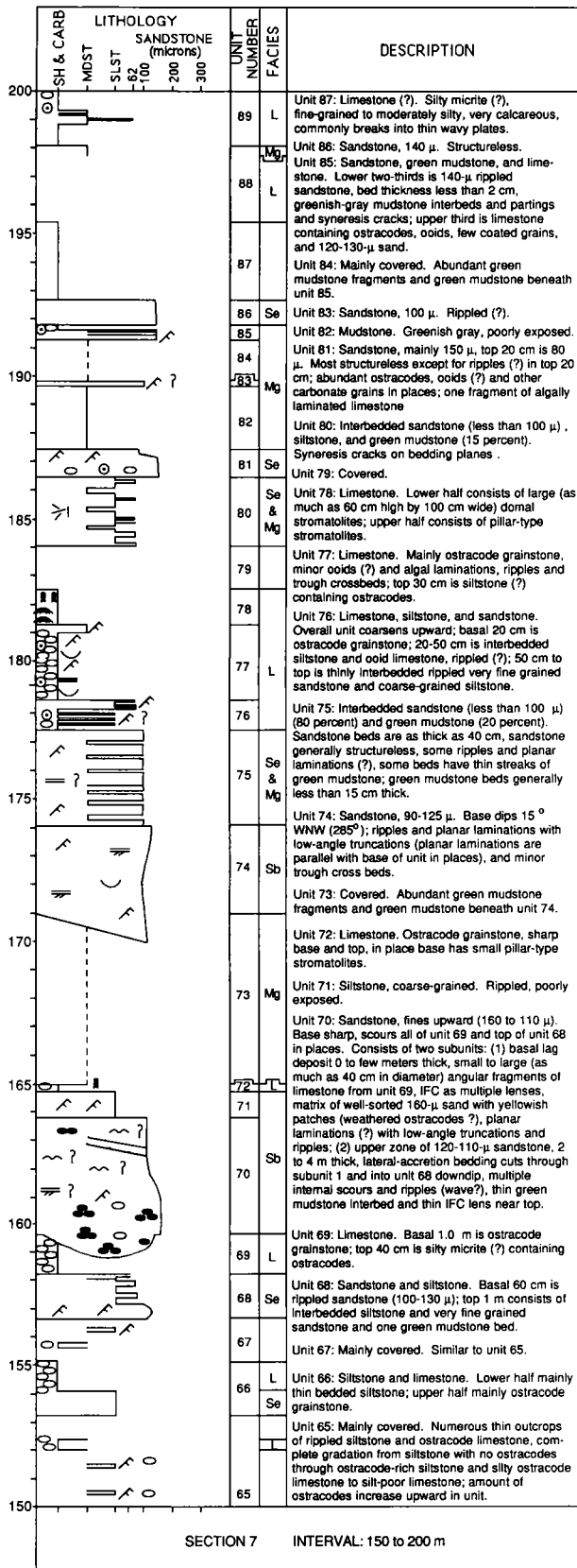


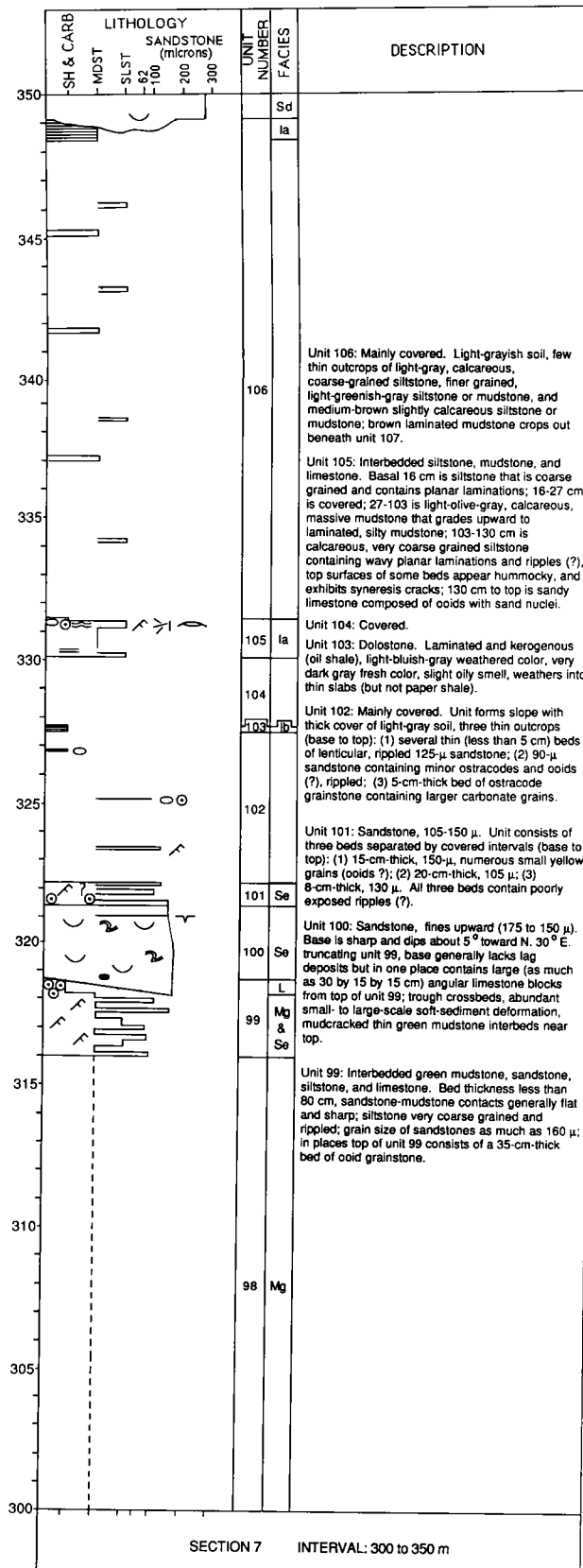
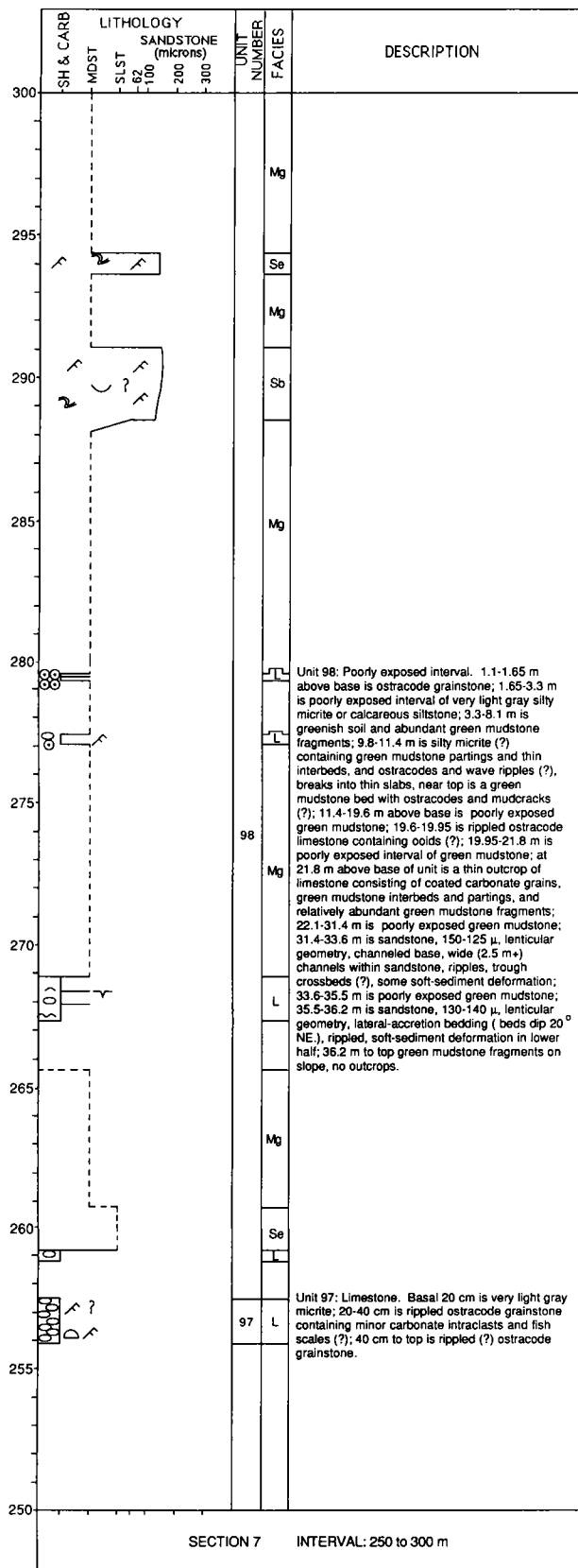




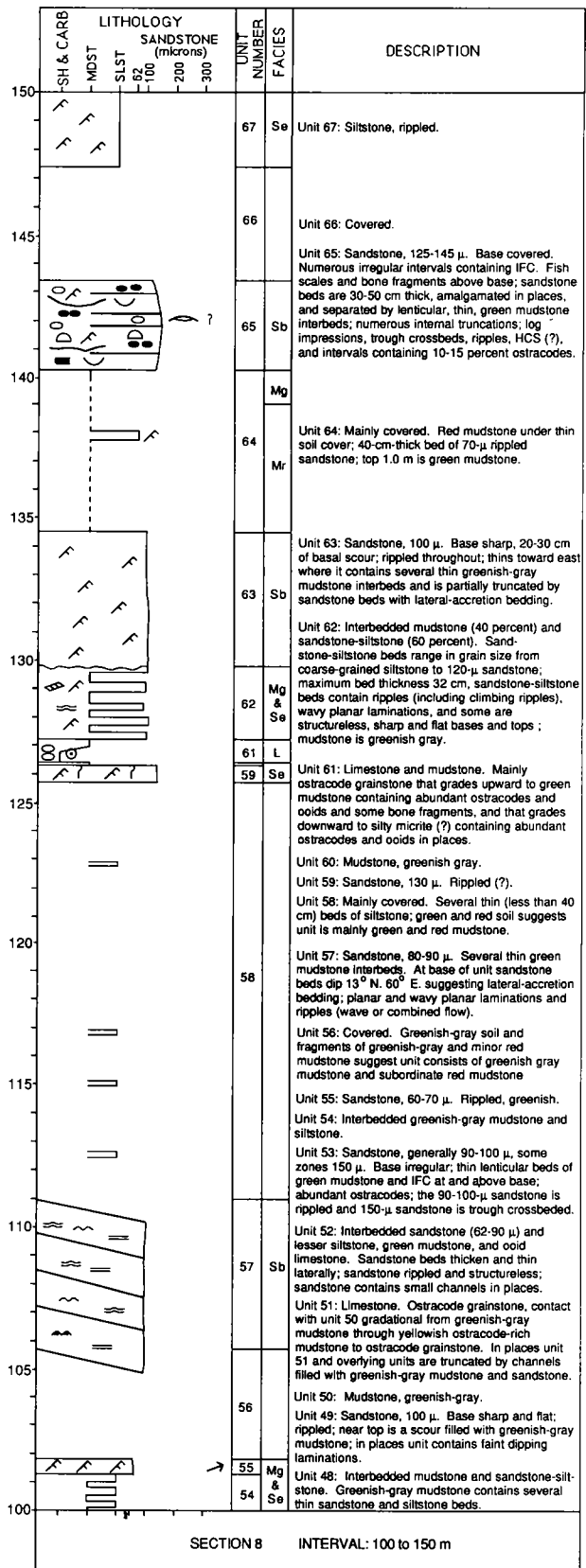
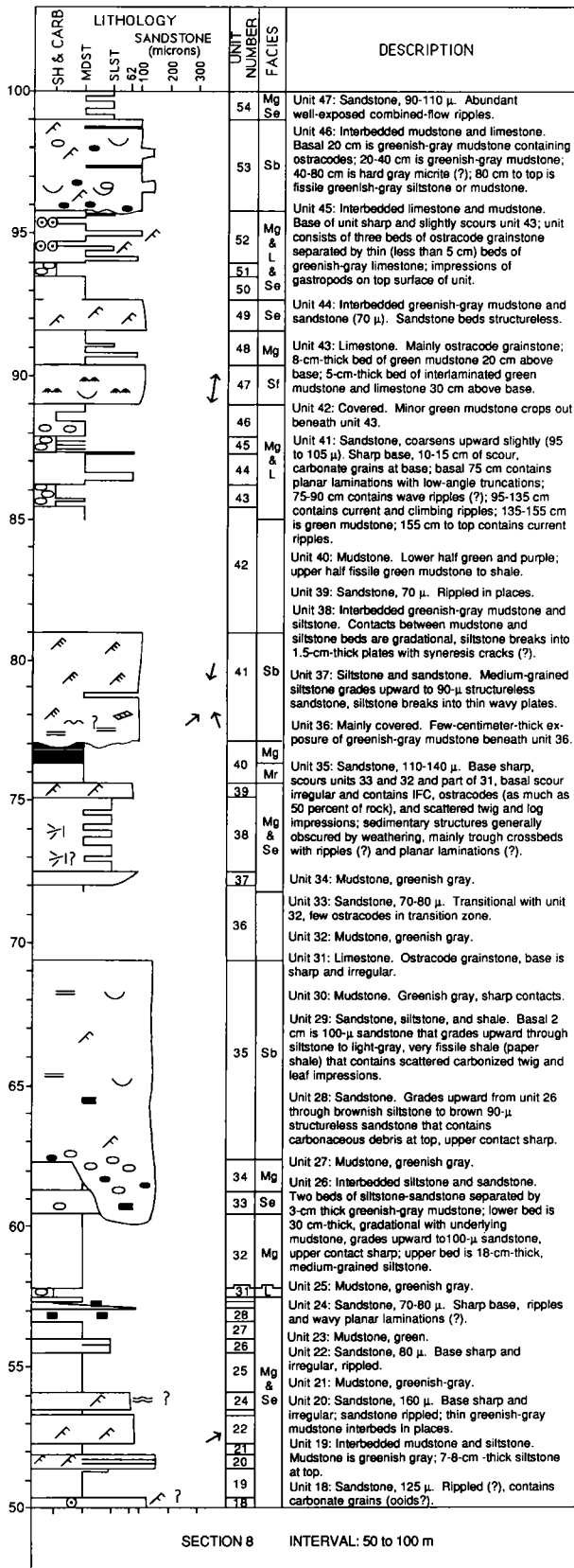


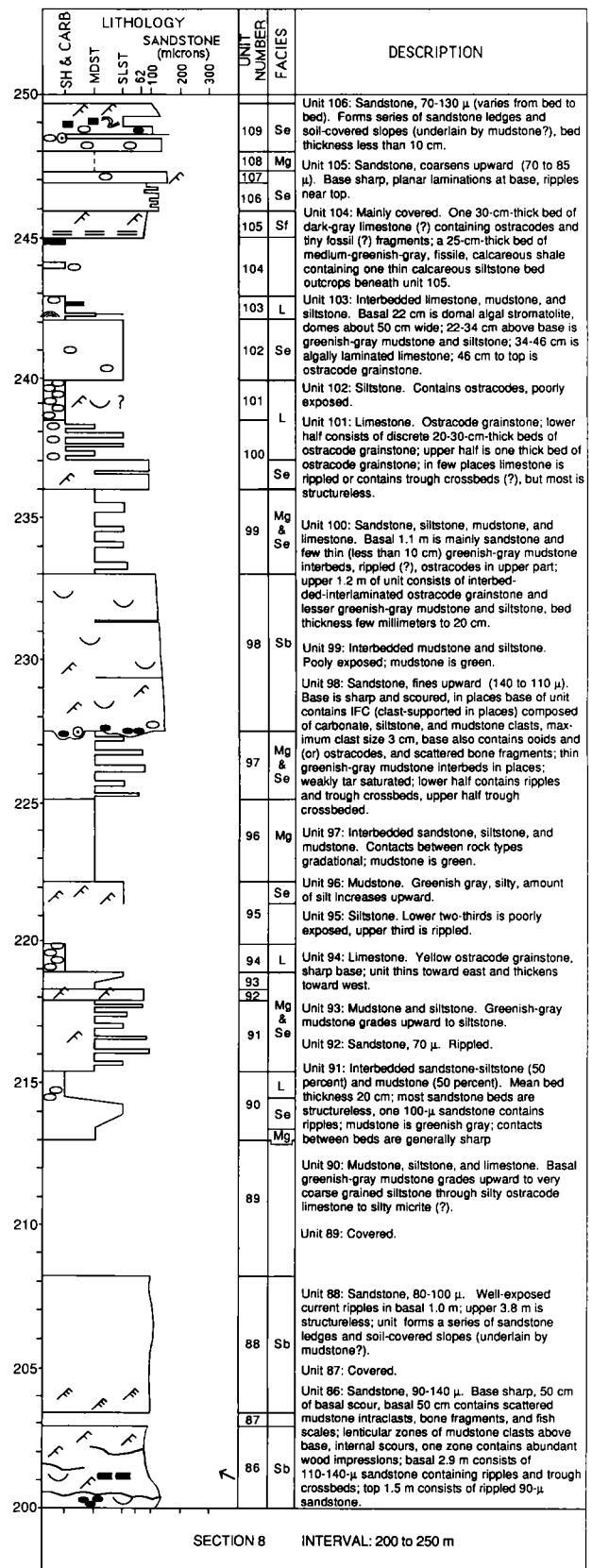
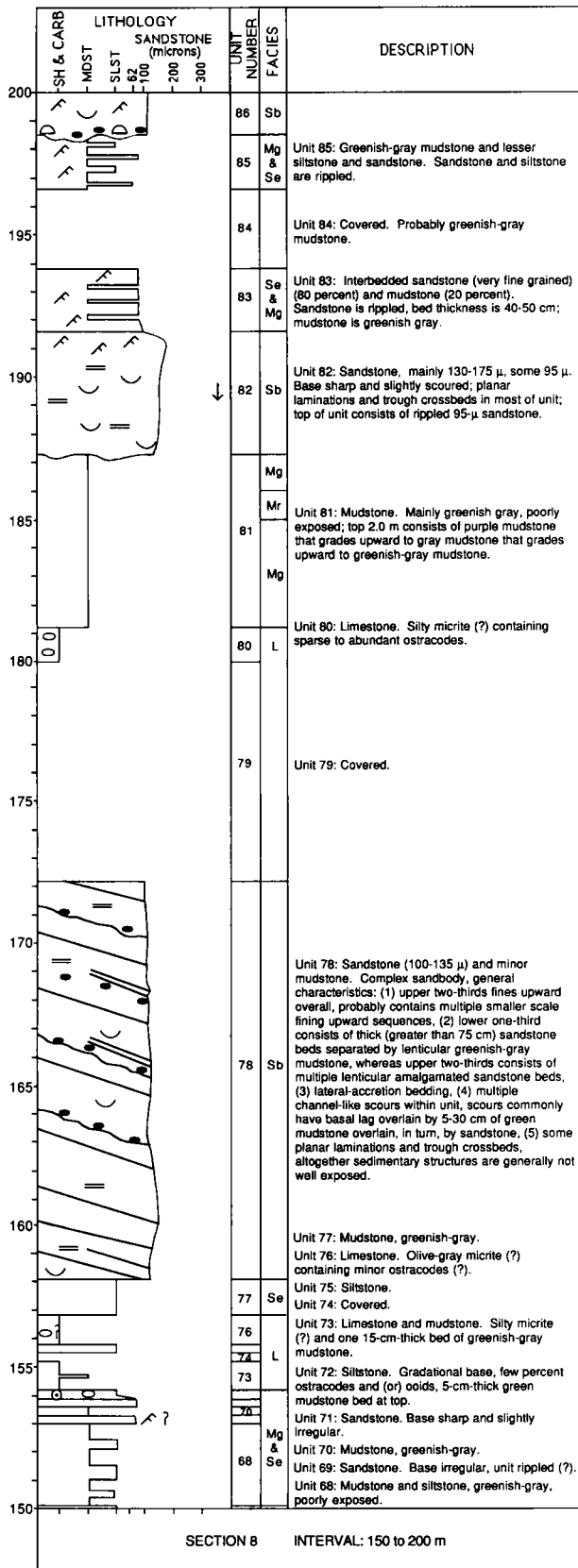


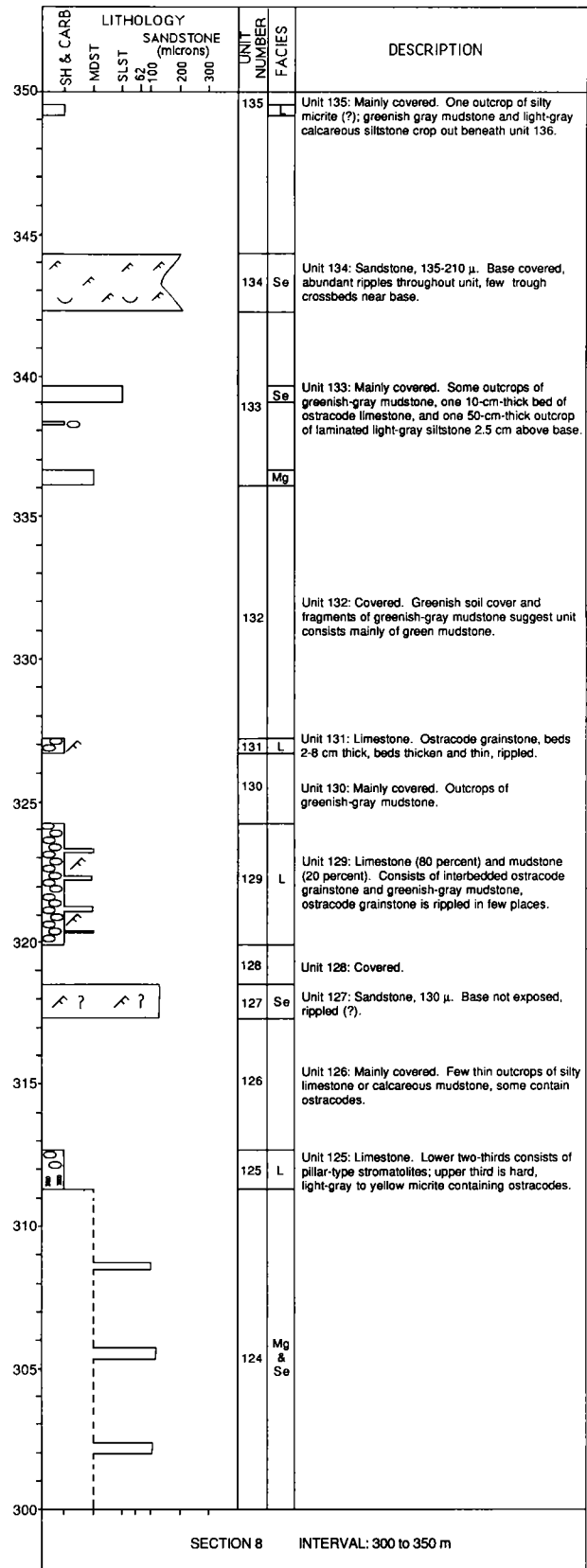
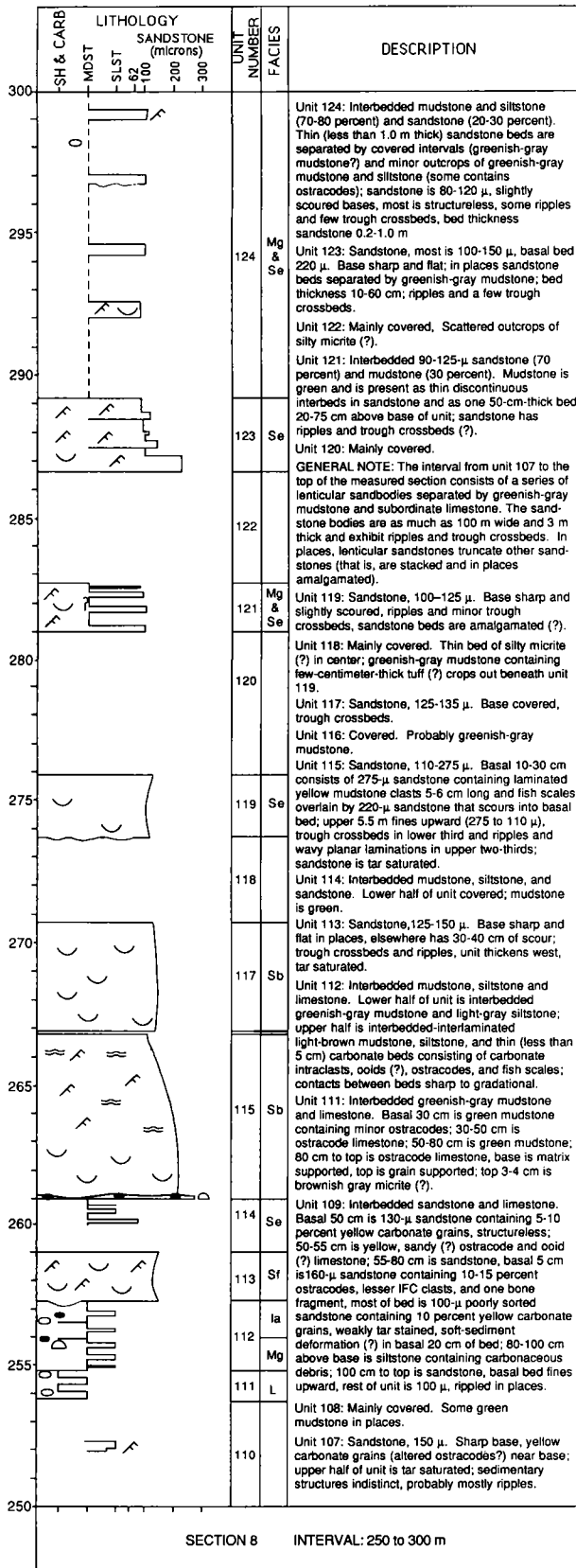


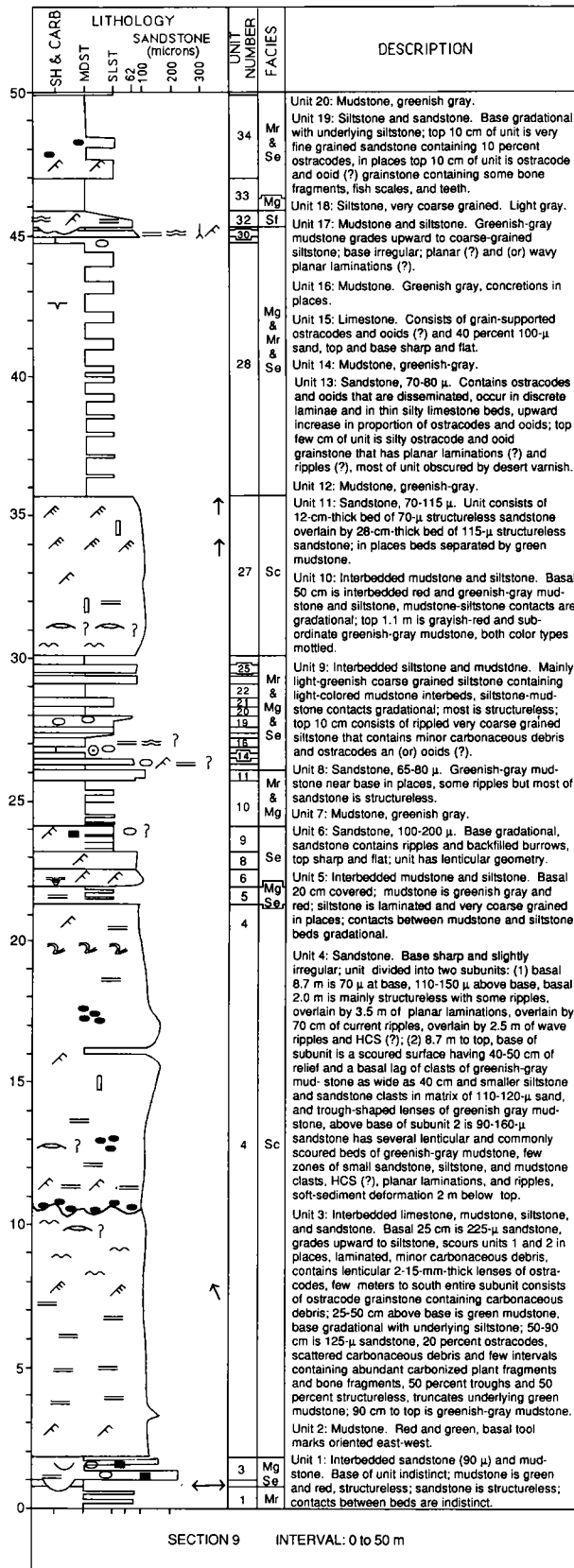
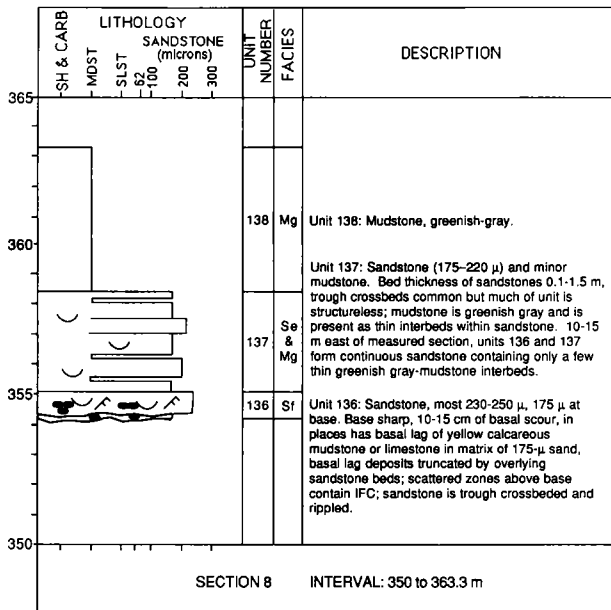


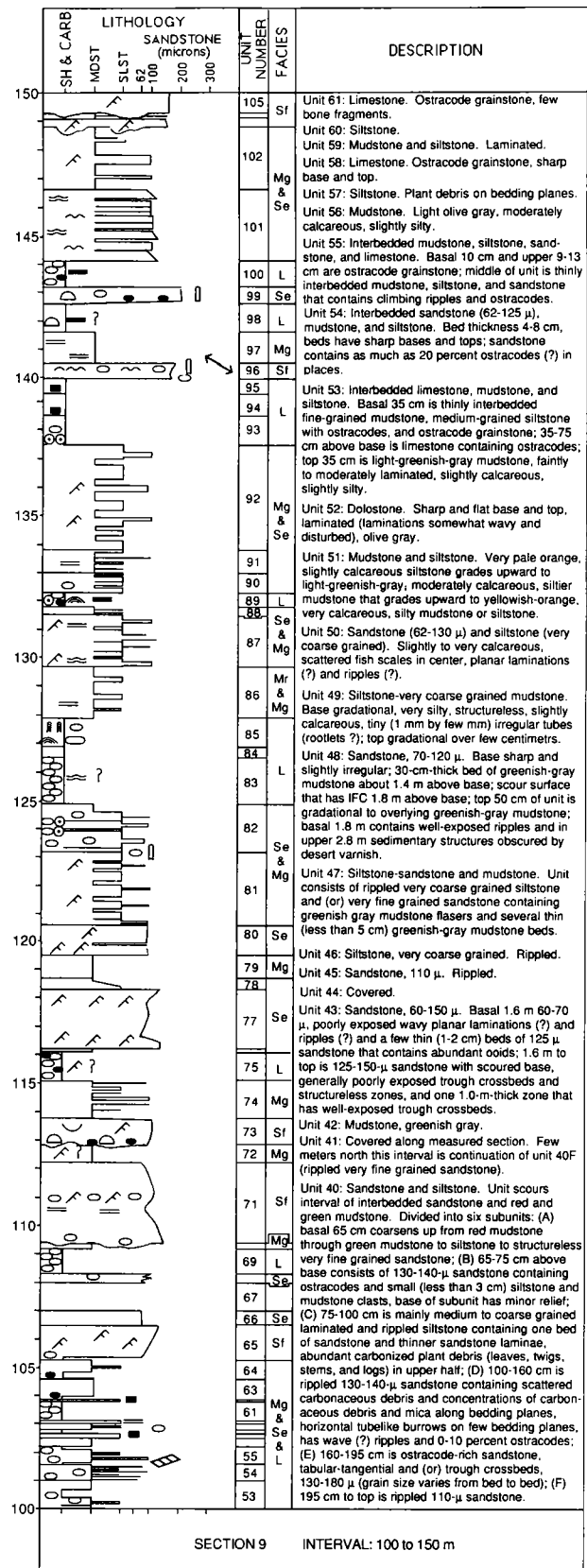
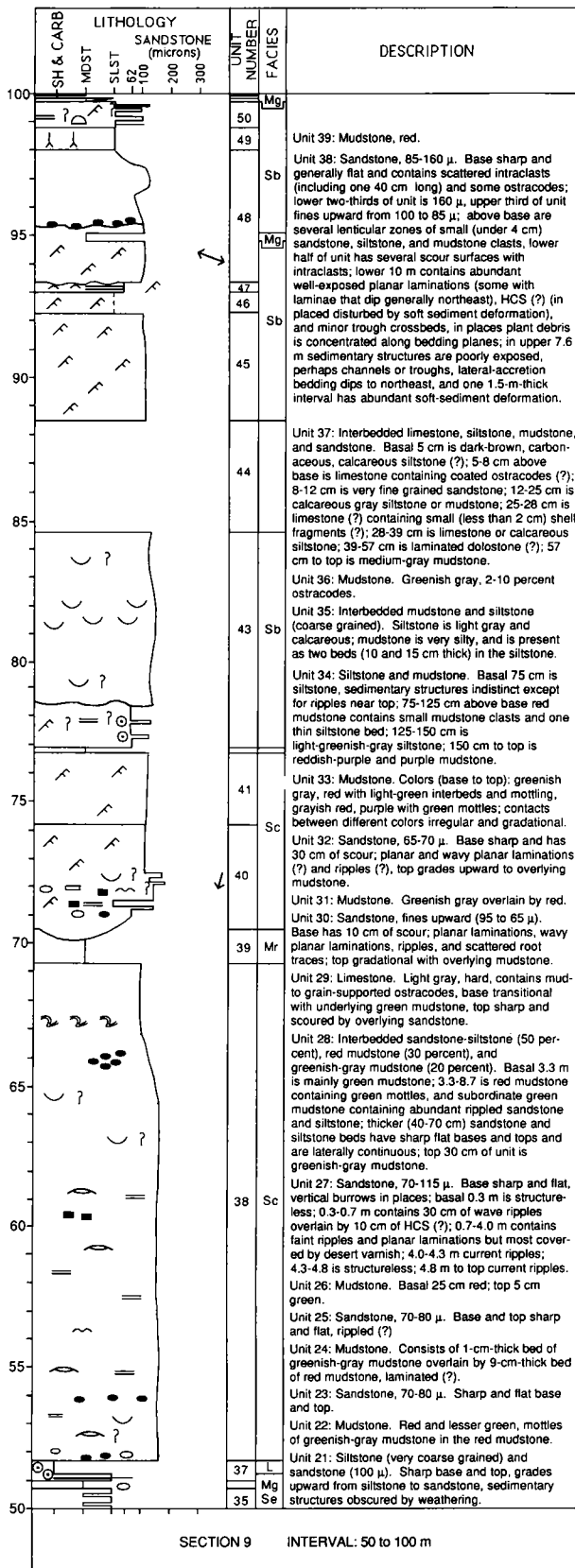




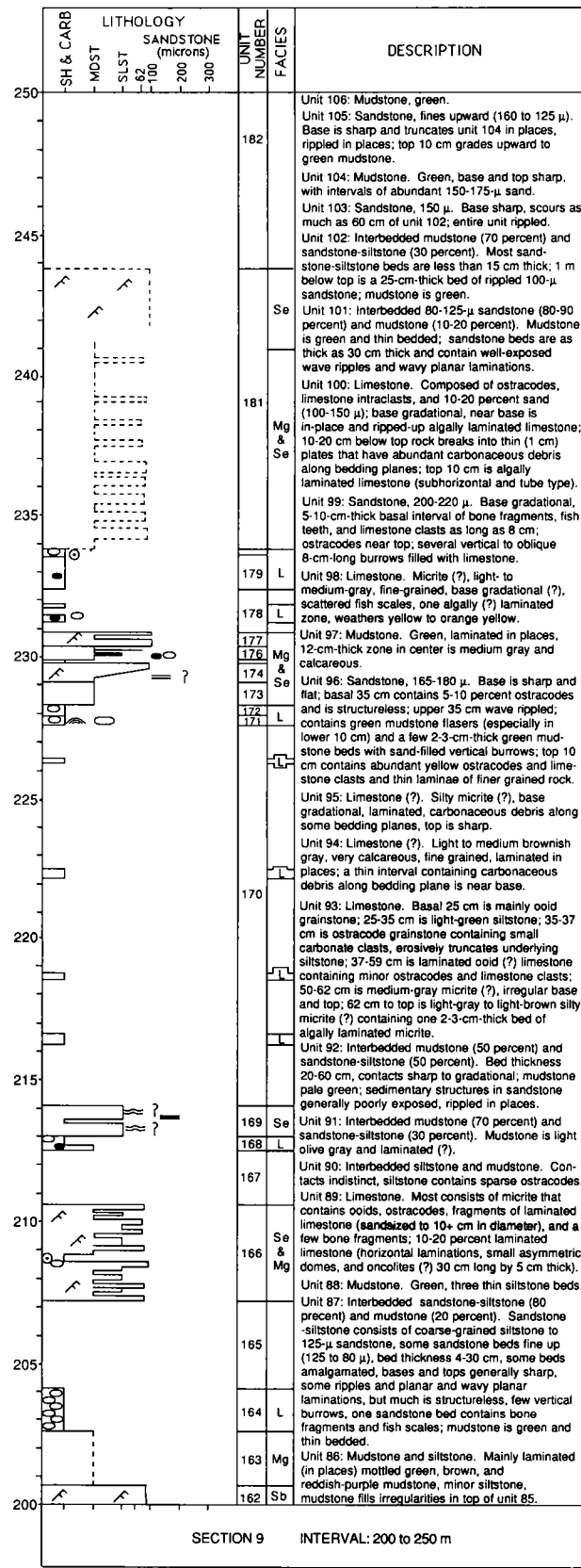
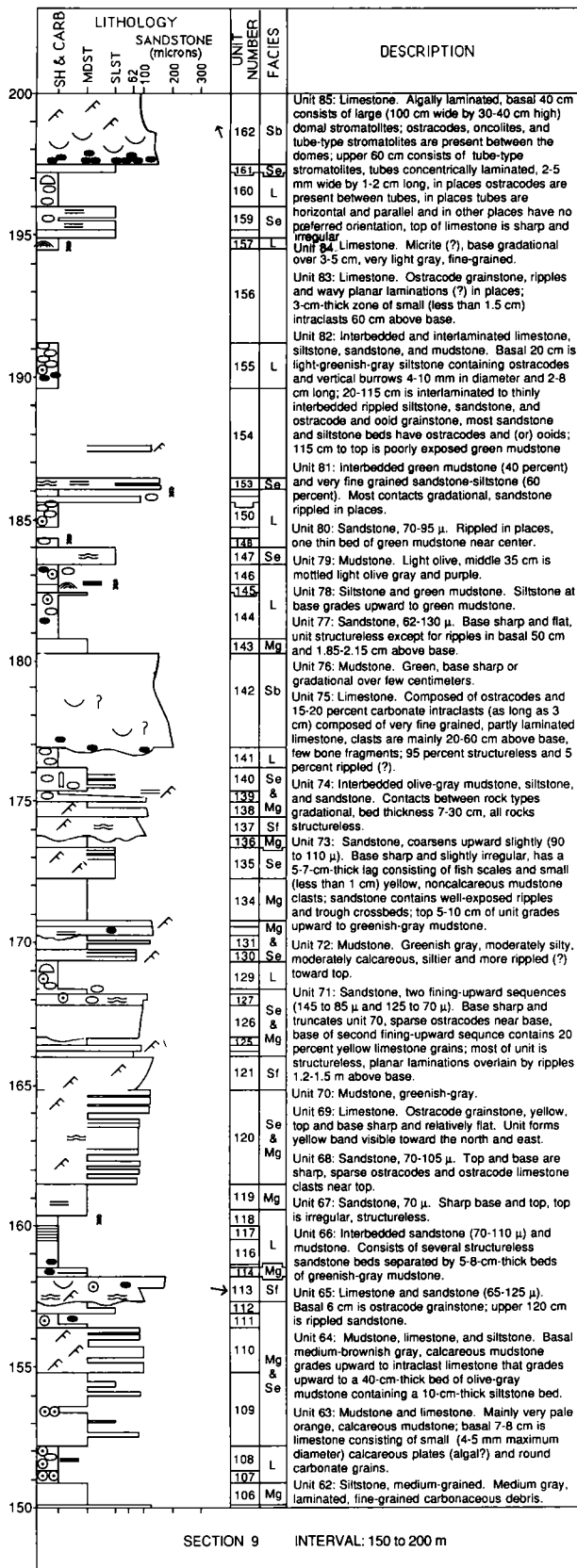


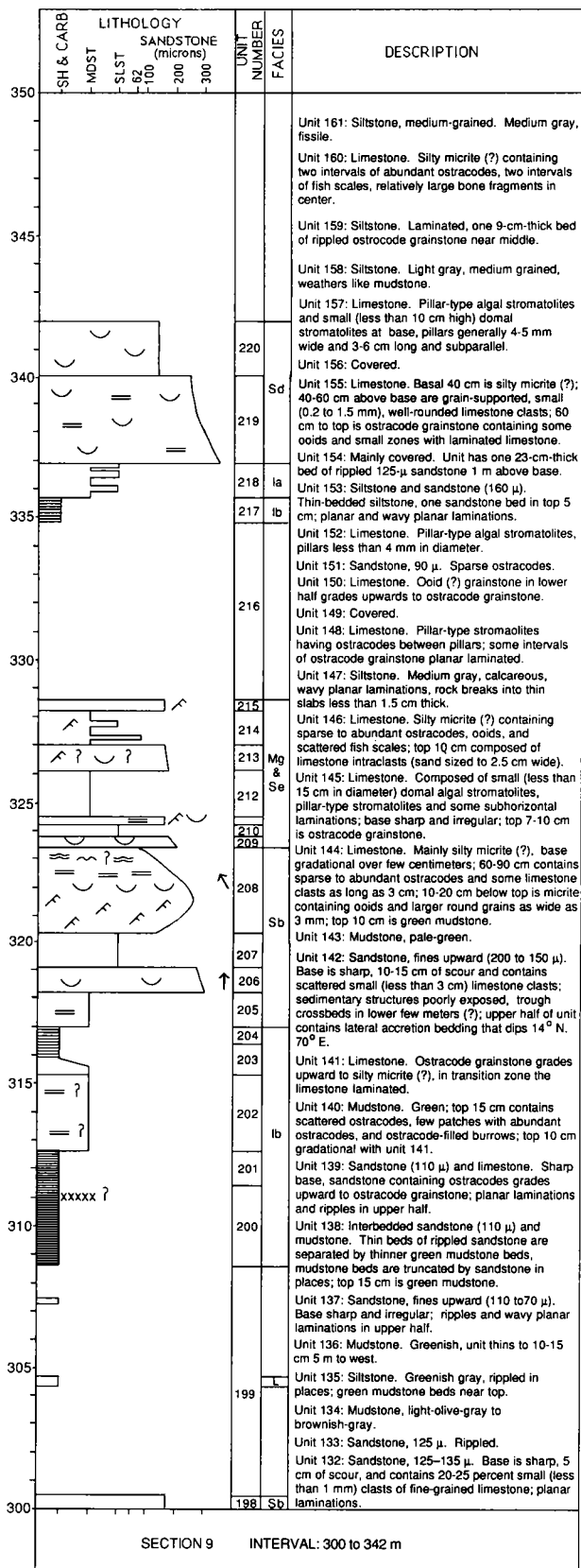
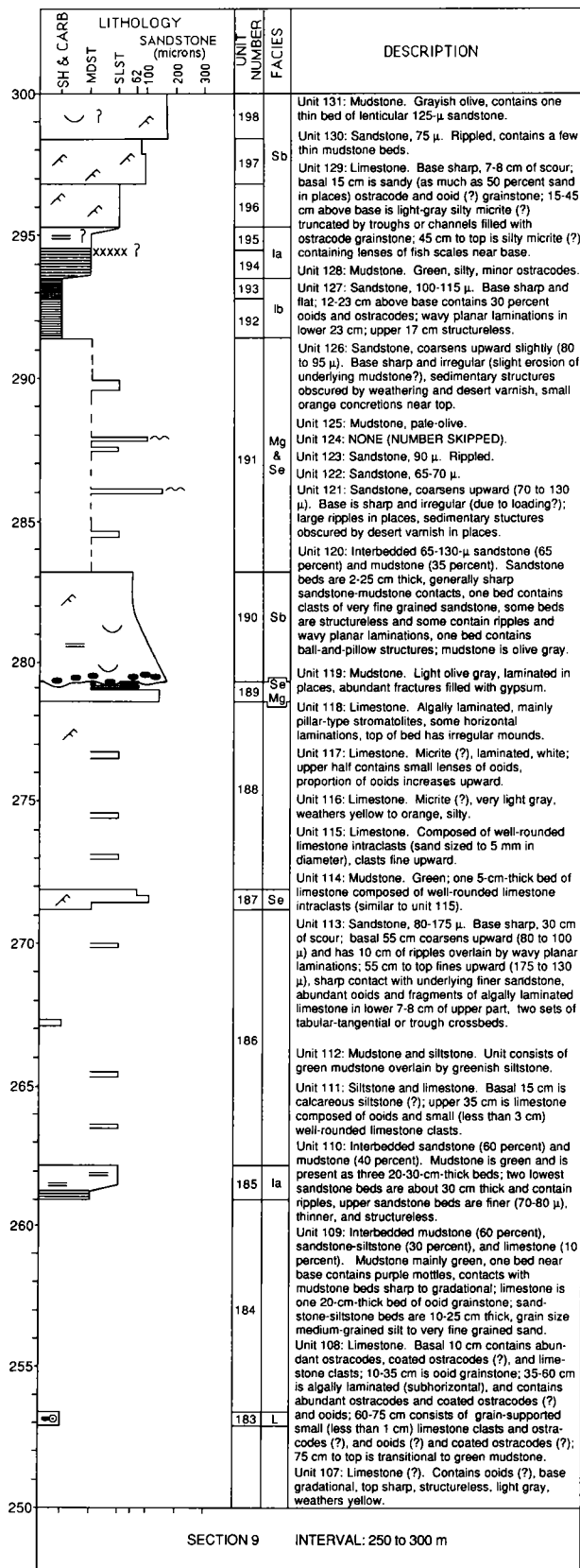






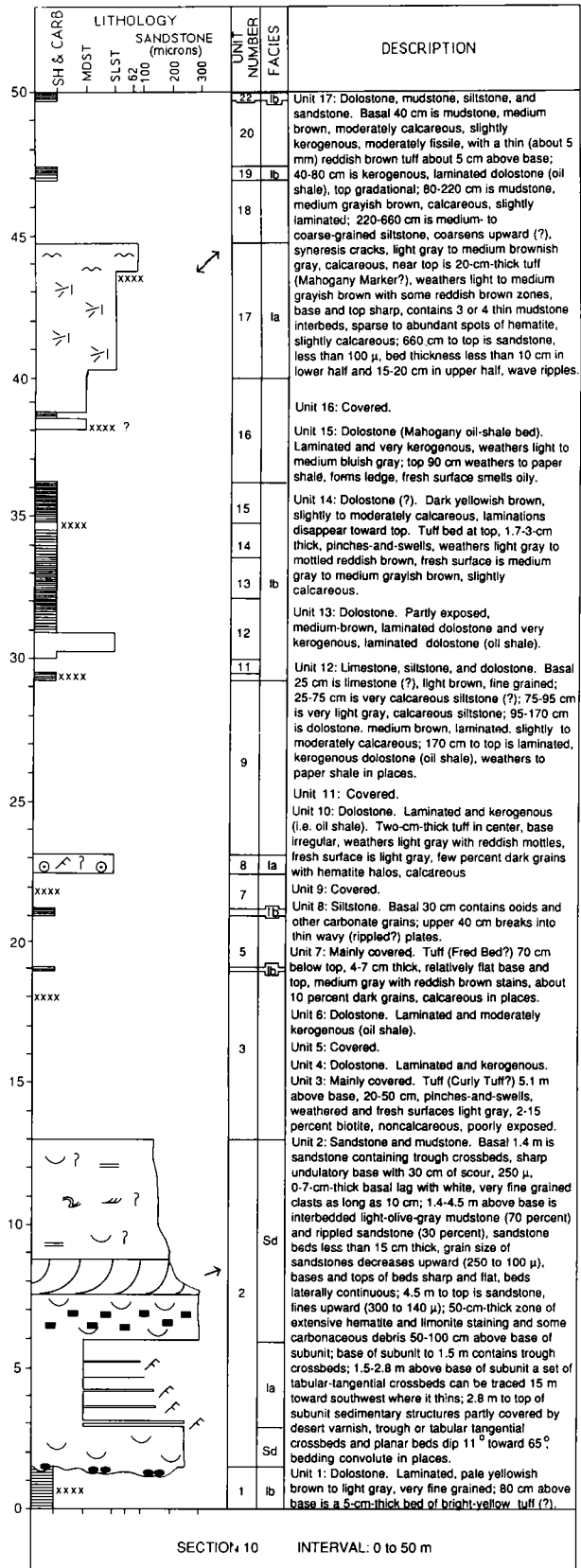


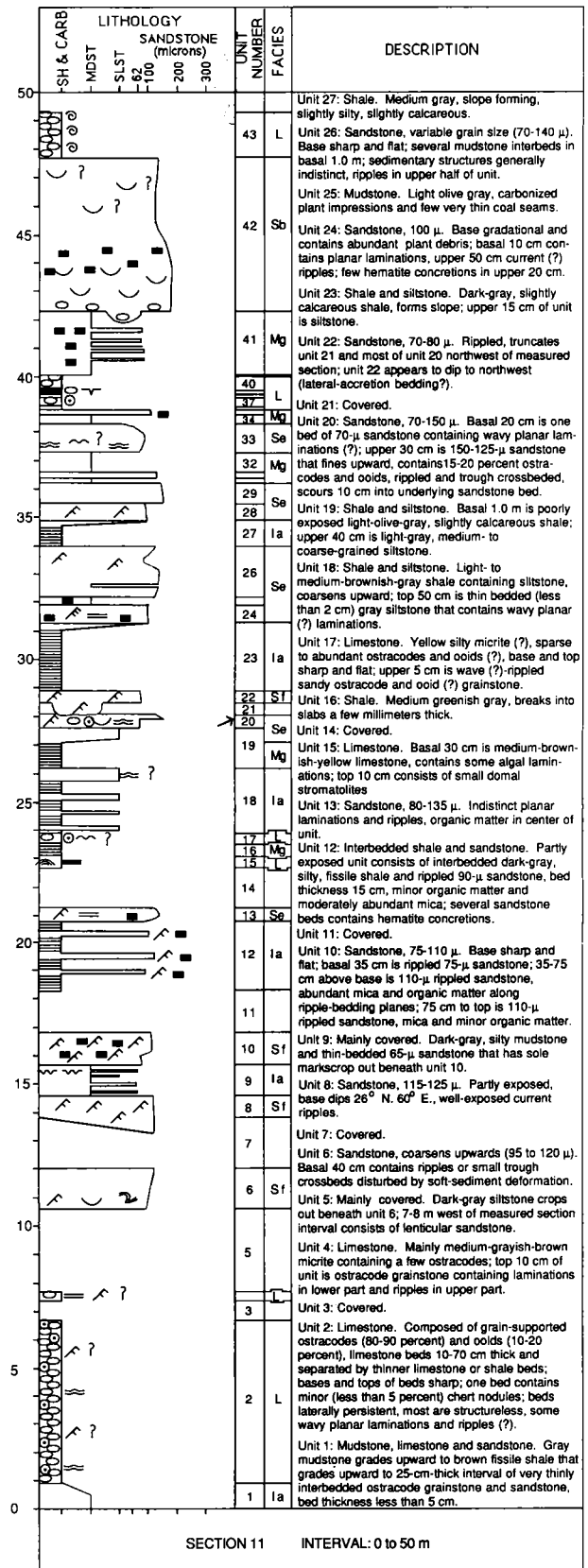
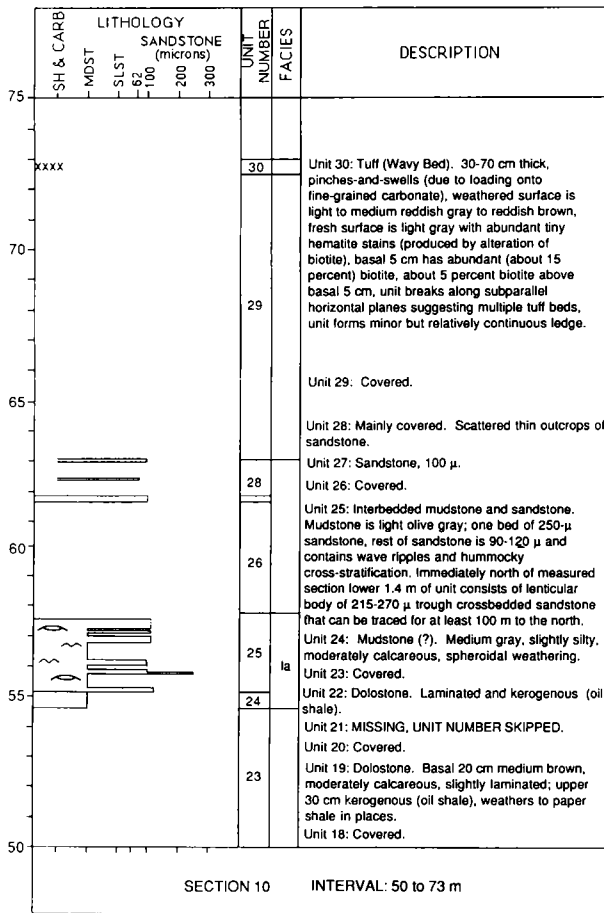


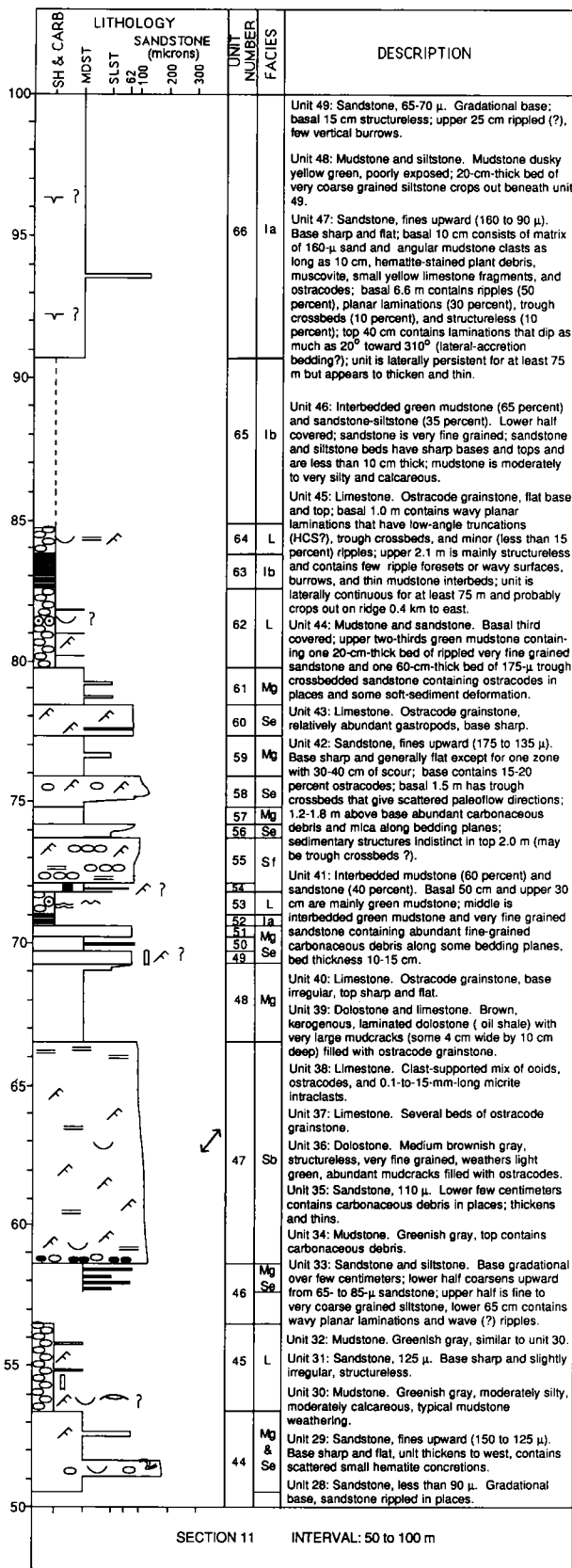


DESCRIPTION Units 162-187	DESCRIPTION Units 188-220
Unit 187: Siltstone (coarse grained) and sandstone (75-100 μ). Basal 25 cm is calcareous siltstone; 25-50 cm is rippled 100-μ sandstone; 50 cm to top is structureless 75-μ sandstone.	Unit 220: Sandstone, 135 μ. Thin bedded, trough crossbeds (at least in places).
Unit 186: Mainly covered. Minor outcrops of light gray laminated siltstone and light-gray carbonate (?) rock.	Unit 219: Sandstone, fines upward (350 250 μ). Base sharp and flat; planar laminations and trough crossbeds.
Unit 185: Mudstone and siltstone. Laminated dark-yellowish-brown mudstone grades upward to laminated, light-gray, fine-grained siltstone that grades upward to coarse-grained light-gray siltstone containing wavy planar laminations.	Unit 218: Siltstone and mudstone. Siltstone is very light gray and medium-grained; mudstone is light to medium brownish gray.
Unit 184: Covered. Abundant float of tar-saturated limestone (some with ooids).	Unit 217: Dolostone. Laminated, medium brownish gray, kerogenous in places.
Unit 183: Limestone. Mainly of fine carbonate grains and larger (as much as 4 cm diameter) grains and zones of brecciated laminated limestone.	Unit 216: Covered.
Unit 182: Covered.	Unit 215: Sandstone, 160 μ. Base sharp and flat; unit rippled in places.
Unit 181: Sandstone and mudstone. Unit covered along section but lower 6.6 m of interval exposed in nearby cliff where it consists of (thicknesses estimated) basal 1.9 m interbedded green mudstone and fine-grained sandstone; 1.9-5.0 m green mudstone and several sandstone-siltstone interbeds; 5-5.3 m unidentifiable bed; 5.3-6.6 rippled 90-μ sandstone.	Unit 214: Interbedded olive mudstone, siltstone, and very fine grained sandstone. Sandstone is rippled.
Unit 180: Limestone. Grain-supported ooids and ostracodes (?), base sharp and irregular.	Unit 213: Sandstone, fines upward slightly (175 to 160 μ). Base sharp and flat; sedimentary structures not well exposed; ripples (?), small trough crossbeds (?), bedding deformed in places.
Unit 179: Limestone. Micrite (?), white, very fine grained, laminated in few places, minor carbonate grains in places.	Unit 212: Mudstone. Olive gray, silty.
Unit 178: Mainly covered. One bed of ostracode and ooid grainstone containing limestone clasts and one 15-cm-thick bed of brownish-gray micrite.	Unit 211: Sandstone, 160 μ. Sharp and flat base; unit thickens north; contains ripples, planar laminations (?), and trough crossbeds (?).
Unit 177: Sandstone (100 μ) and mudstone. Rippled sandstone breaks into slabs 2-8 cm thick; 15-cm-thick bed of fissile green mudstone 10-25 cm from top.	Unit 210: Siltstone.
Unit 176: Mudstone and siltstone. Basal 20 cm is fissile green mudstone; upper 30 cm is interbedded mudstone and siltstone.	Unit 209: Sandstone, fines upward (200 to 175 μ). Base sharp and flat, trough crossbeds.
Unit 175: Limestone. Base sharp; composed of ostracodes, small round carbonate grains (no nuclei or concentric layering), and larger, more angular limestone clasts.	Unit 208: Sandstone, variable grain size (75-260 μ). Base sharp and flat; basal 1.2 m rippled; 1.2-2.0 m is trough crossbedded; 2.0-2.5 m is planar laminated; 2.5 m to top is wave rippled (?) and wavy planar laminated.
Unit 174: Siltstone and sandstone. Base grades upward from mudstone to 90-μ sandstone; top grades upward to coarse-grained siltstone; contains planar laminations (?) and ripples (?).	Unit 207: Siltstone, olive-gray.
Unit 173: Mudstone, greenish-gray.	Unit 206: Sandstone, fines upward (300 to 250 μ). Base sharp and flat, faint trough crossbeds.
Unit 172: Limestone. Basal 20 cm is light yellowish gray, composed of silt- to very fine sand-sized carbonate grains and less than 10 percent ostracodes; upper 20 cm is interbedded limestone composed of ostracodes and other carbonate grains and limestone similar to basal 20 cm.	Unit 205: Mudstone. Olive-brown, silty, laminated.
Unit 171: Limestone. Oncolites, angular fragments of laminated limestone, and small domal stromatolites in matrix of fine-grained limestone containing ostracodes.	Unit 204: Dolostone. Very dark gray, laminated on weathered surfaces.
Unit 170: Mainly covered. Few outcrops of thin bedded to laminated limestone, abundant green mudstone float on surface.	Unit 203: Mudstone and dolostone. Medium-brownish-gray, moderately calcareous mudstone grades upward to very dark gray dolostone that appears laminated on weathered surfaces.
Unit 169: Siltstone and limestone. Siltstone is light gray and moderately calcareous, contains wavy planar laminations (?), breaks into slabs 2-10 mm thick, one 0-15-cm-thick bed of laminated (algal?) limestone disrupts siltstone bedding.	Unit 202: Mudstone. Light to medium brownish gray, moderately calcareous, fine grained to moderately silty, weathers very light gray, some zones are laminated (?) on weathered surfaces.
Unit 168: Mudstone and limestone. Basal 20 cm is green mudstone containing limestone clasts and thin limestone interbeds; basal mudstone grades upward to limestone composed of ostracodes and small (100 μ-1 cm diameter), spherical to oval limestone clasts.	Unit 201: Dolostone. Laminated, very kerogenous (oil shale), weathers to paper shale in places.
Unit 167: Covered.	Unit 200: Dolostone. Laminated and moderately kerogenous (oil shale), weathers to paper shale in places; 2-cm-thick tuff (?) near top.
Unit 166: Siltstone, sandstone, and mudstone. Much of unit covered; abundant siltstone and wave-rippled sandstone (65-150 μ), and olive-gray mudstone in places.	Unit 199: Mainly covered. Few thin outcrops of brown dolostone.
Unit 165: Covered.	Unit 198: Sandstone, 170 μ. Base sharp and scours underlying sandstone; most structureless, well-exposed ripples in places and trough crossbeds in lower half (?).
Unit 164: Limestone. Ostracode grainstone.	Unit 197: Sandstone, 70-90 μ. Basal two-thirds is 90 μ and rippled; upper third is 70-80 μ, forms recess.
Unit 163: Mudstone. Green, poorly exposed.	Unit 196: Siltstone, medium- to coarse-grained. Base gradational over 15 cm with underlying mudstone, rippled in places.
Unit 162: Sandstone, fines upward (160 to 85 μ). Base sharp and flat; basal 0-50 cm contains abundant (clast supported in places), small (2.5 cm maximum diameter), well-rounded limestone clasts in matrix of 140-160-μ sand; IFC overlain by 75-100-cm interval of trough crossbeds overlain by ripples; top of unit contains abundant chert pebbles and fish scales.	Unit 195: Mudstone. Sharp base; light-brownish-gray, moderately calcareous mudstone grades upward to very light gray, slightly calcareous mudstone; unit weathers white and is laminated (?) in places.
	Unit 194: Mudstone. Olive-gray, laminated, gradational contact (over 20 cm) with underlying laminated dolostone; 50 cm from top an 8-cm-thick bed of orange-red rock (tuff ?) has sharp base and top and irregular bedding.
	Unit 193: Dolostone. Laminated; basal 20 cm moderately kerogenous (oil shale).
	Unit 192: Dolostone. Laminated and very kerogenous (oil shale), weathers to paper shale in places.
	Unit 191: Siltstone, sandstone, and mudstone. Much of unit covered; abundant siltstone and wave-rippled sandstone (65-150 μ), and olive-gray mudstone in places.
	Unit 190: Sandstone, fines upward (175 to 150 μ). Base sharp, less than 30 cm of scour; 0-40-cm-thick zone containing mudstone clasts at base; most of unit structureless, minor trough crossbeds, ripples, and planar laminations.
	Unit 189: Sandstone-siltstone and mudstone. Three 13-18-cm-thick beds of 140-μ sandstone overlain by 20-cm-thick interval of interbedded green mudstone and coarse-grained siltstone.
	Unit 188: Mainly covered. Several outcrops of laminated to thinly bedded, light-gray calcareous siltstone; 50-cm-thick bed of dusky-yellow-green mudstone crops out beneath unit 189.

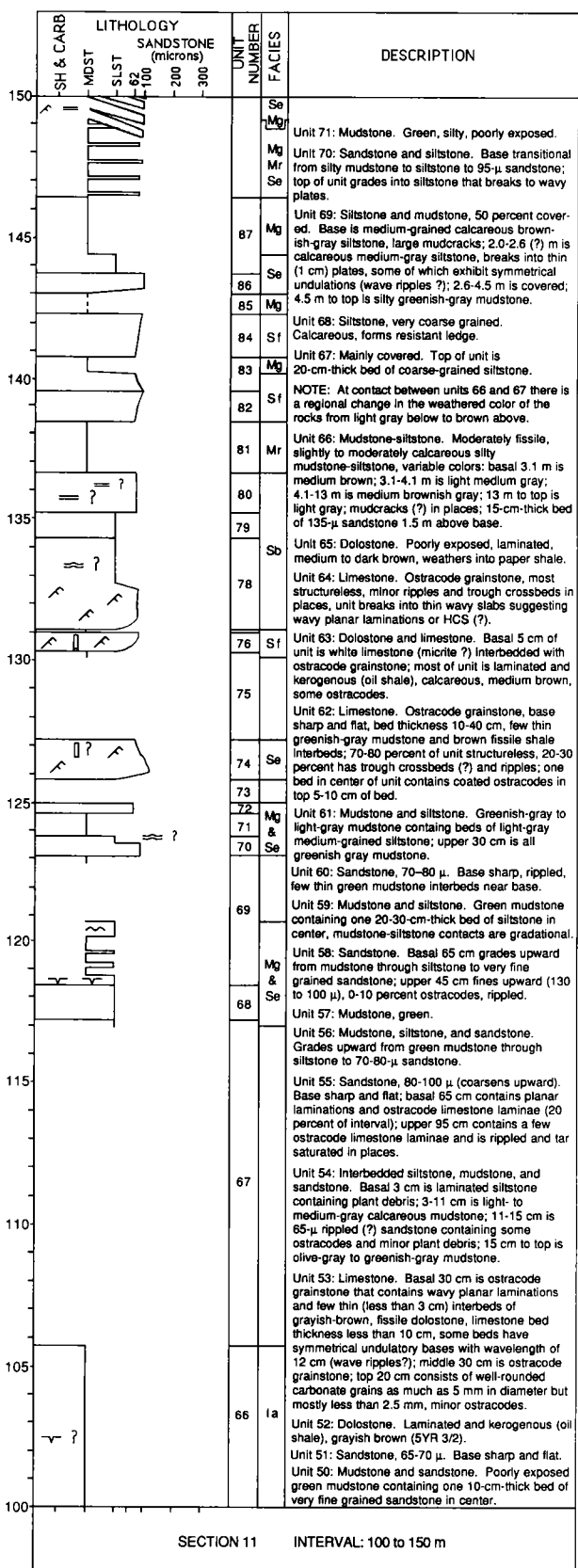
SECTION 9 DESCRIPTION ONLY



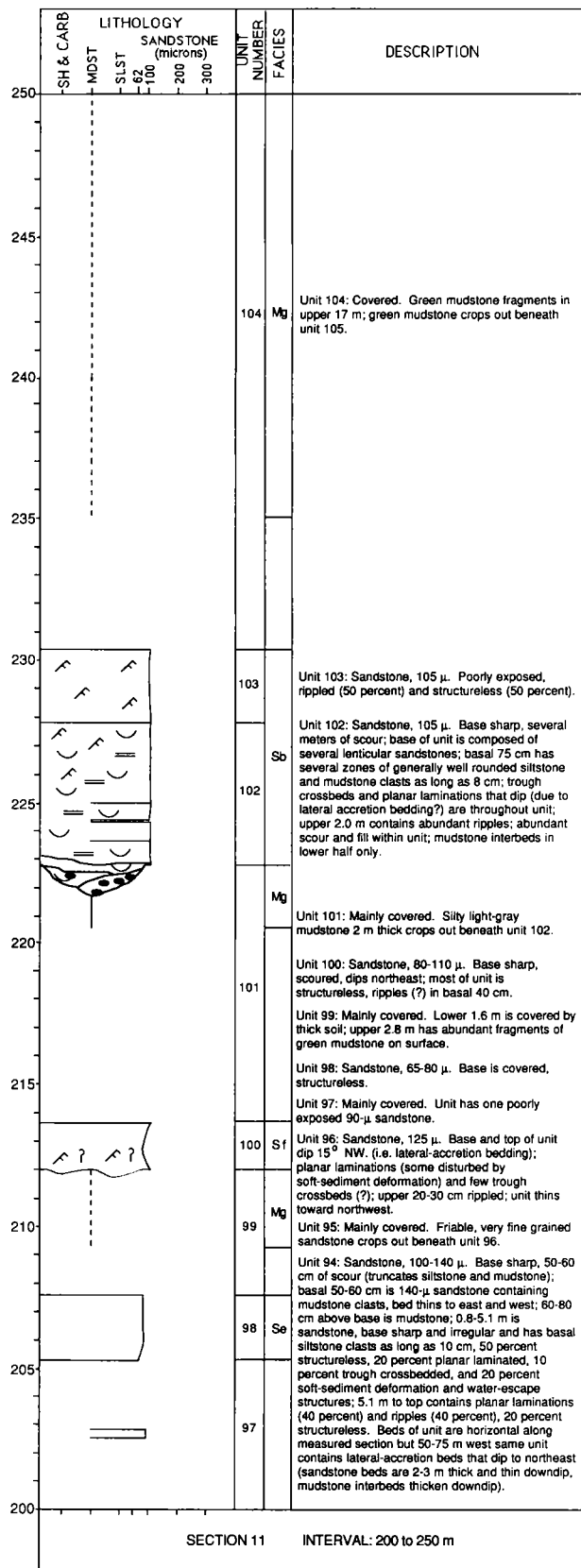
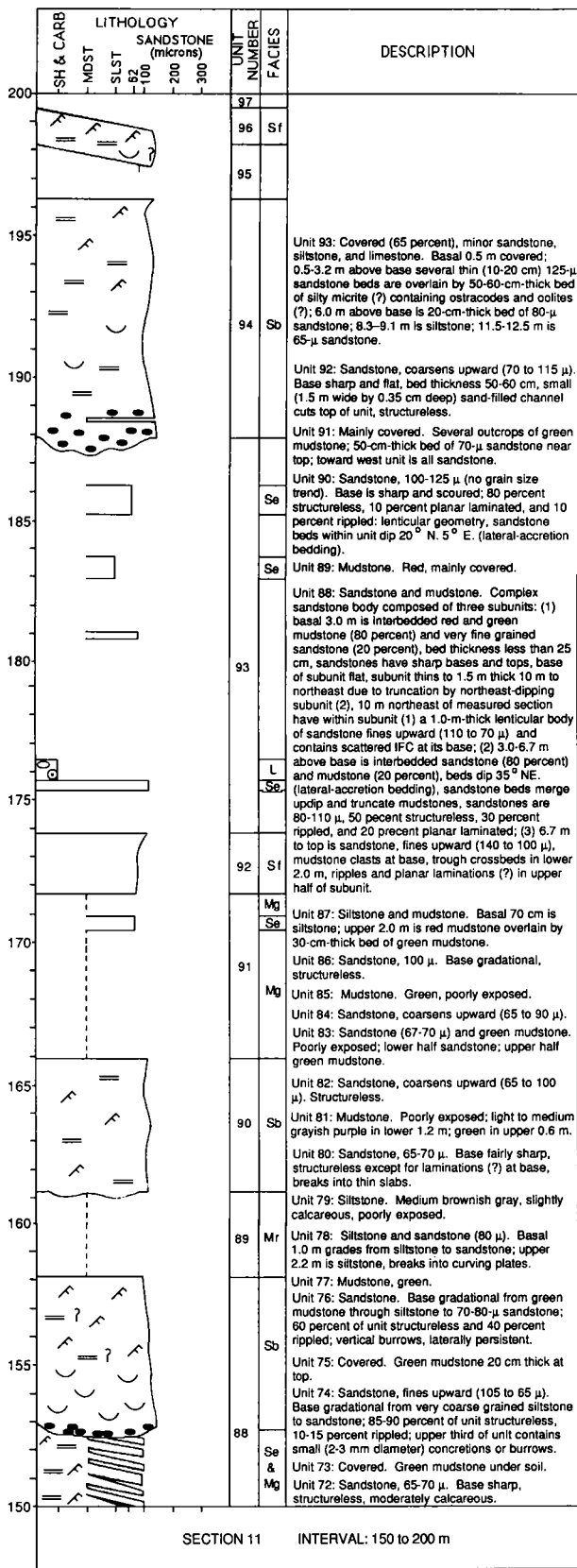


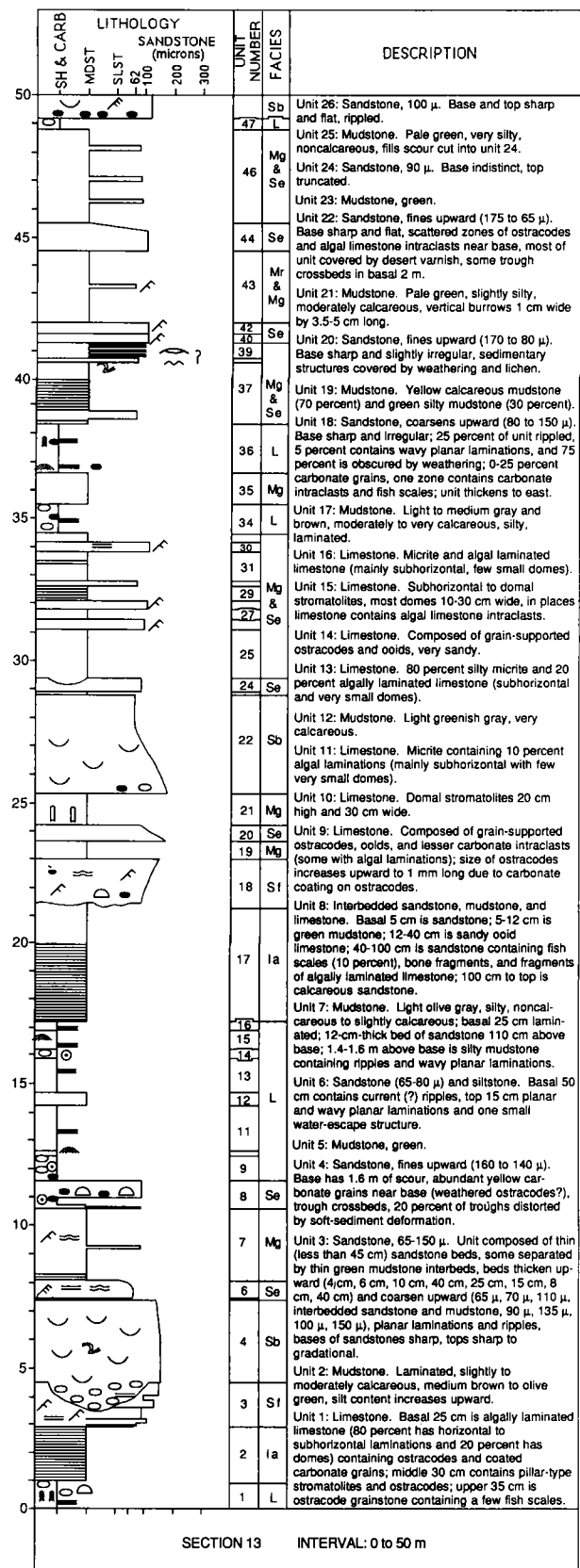
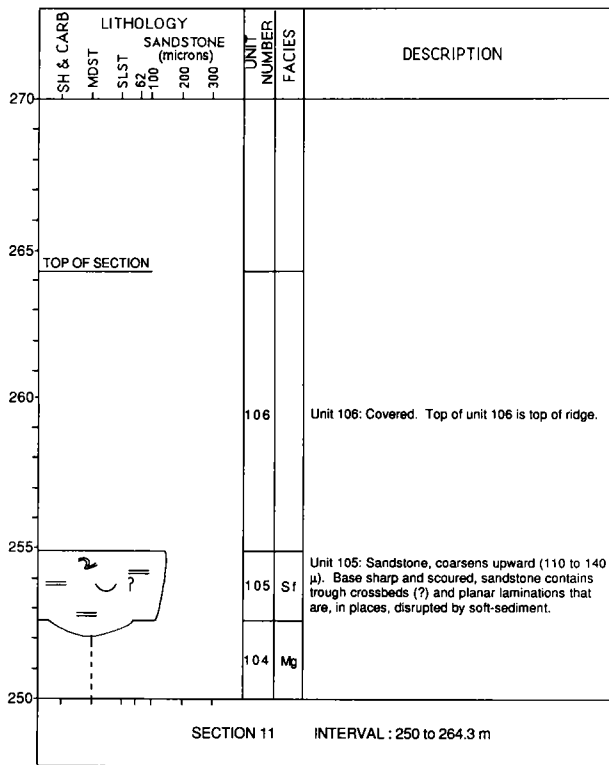


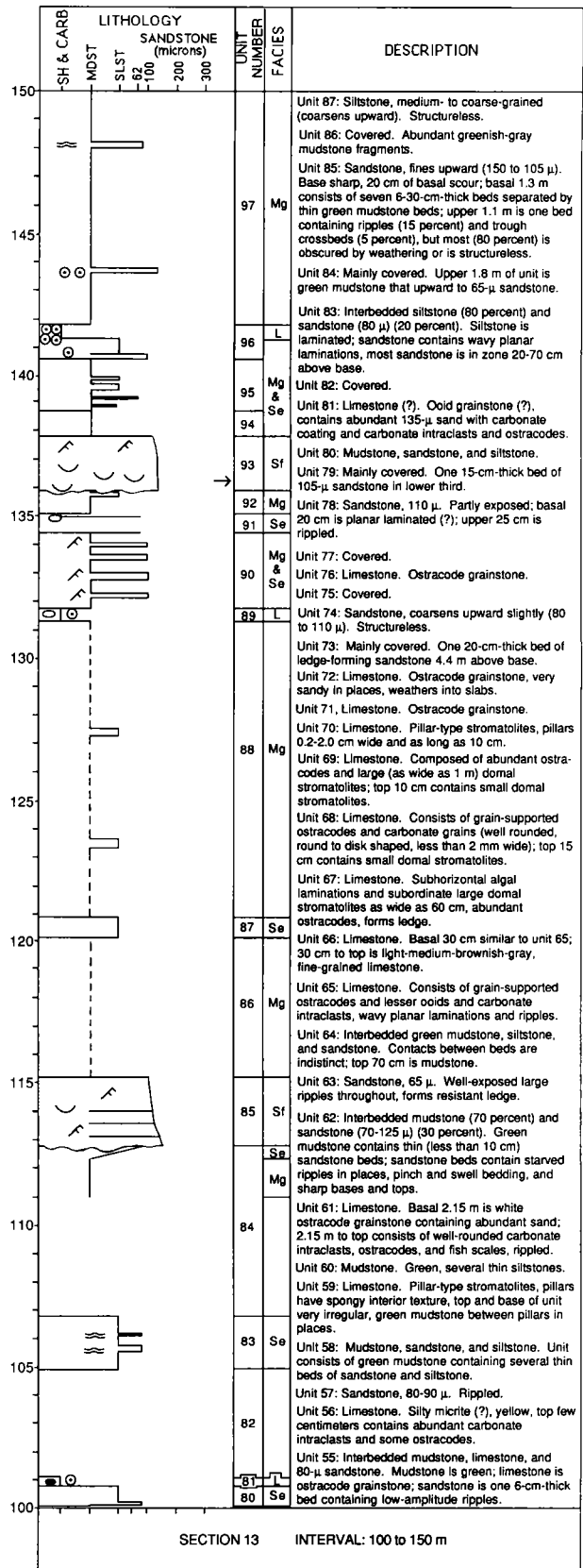
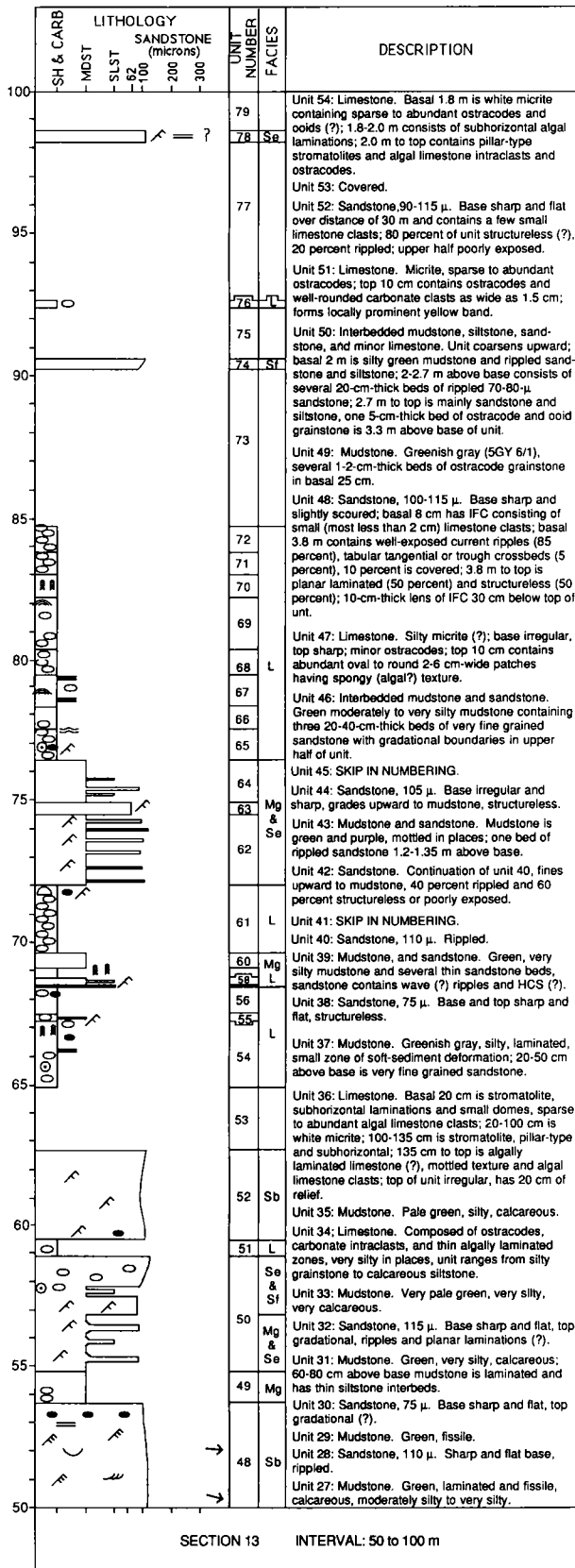
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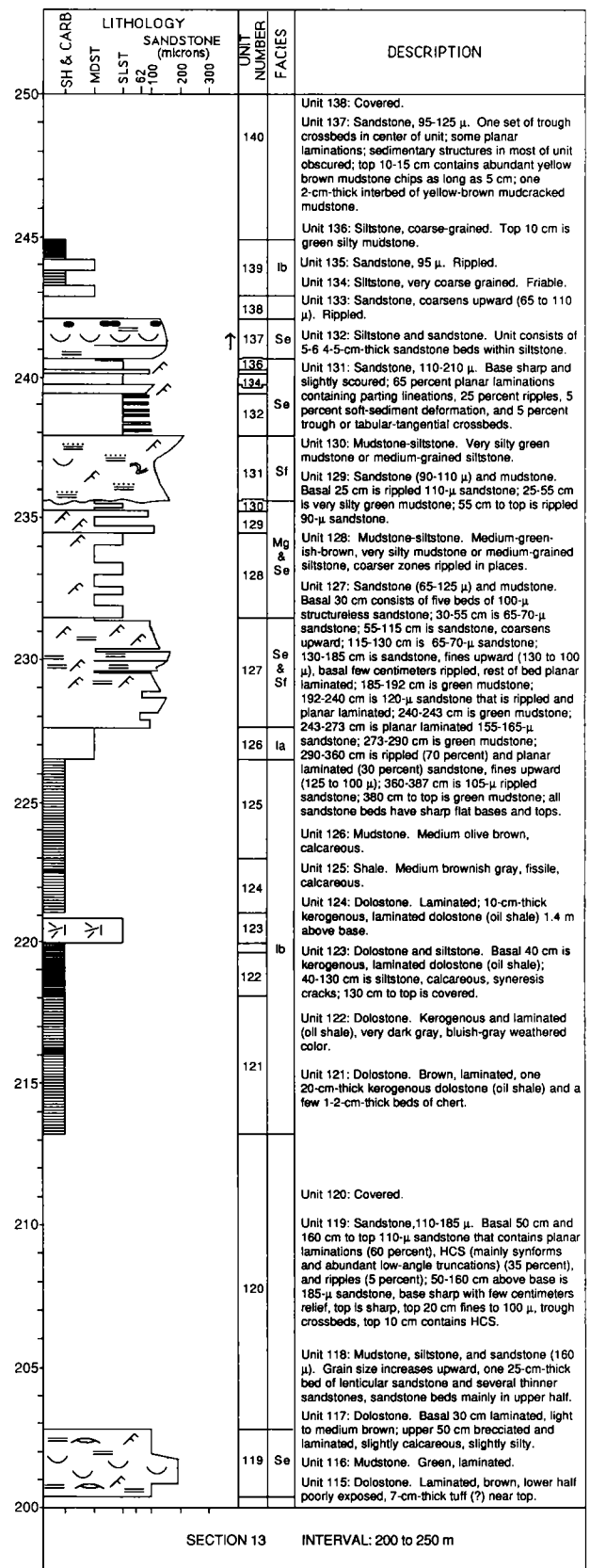
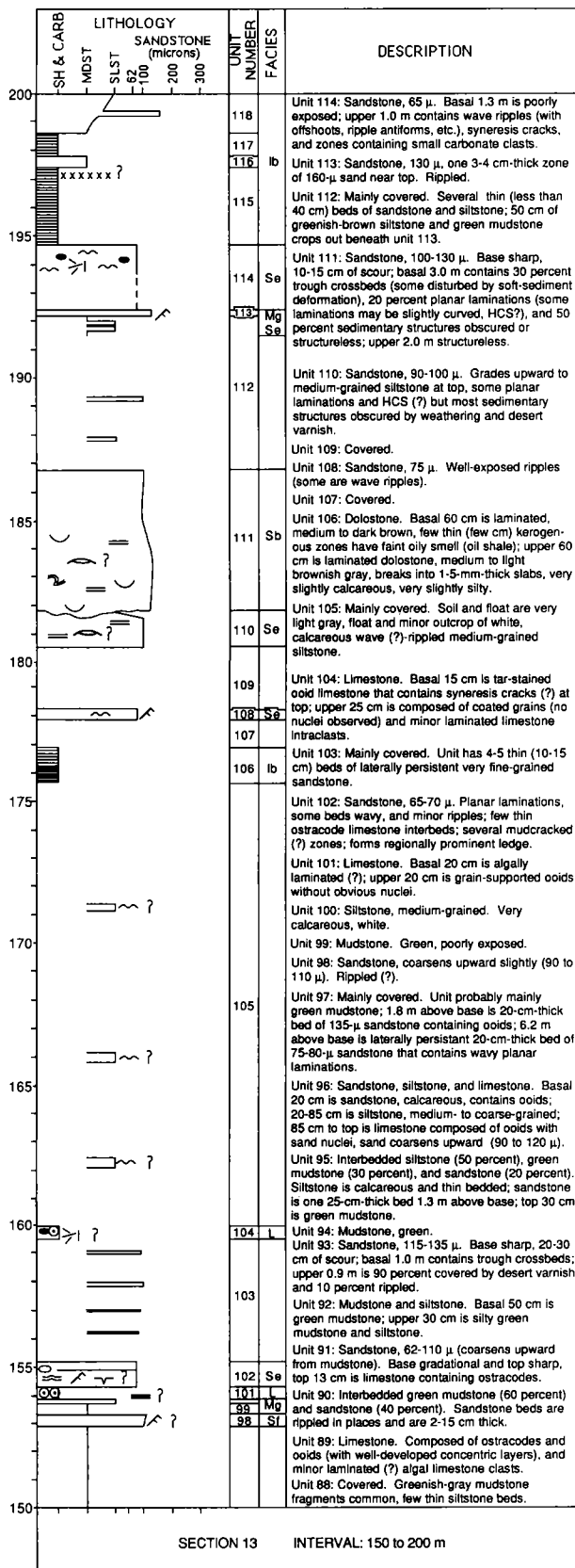
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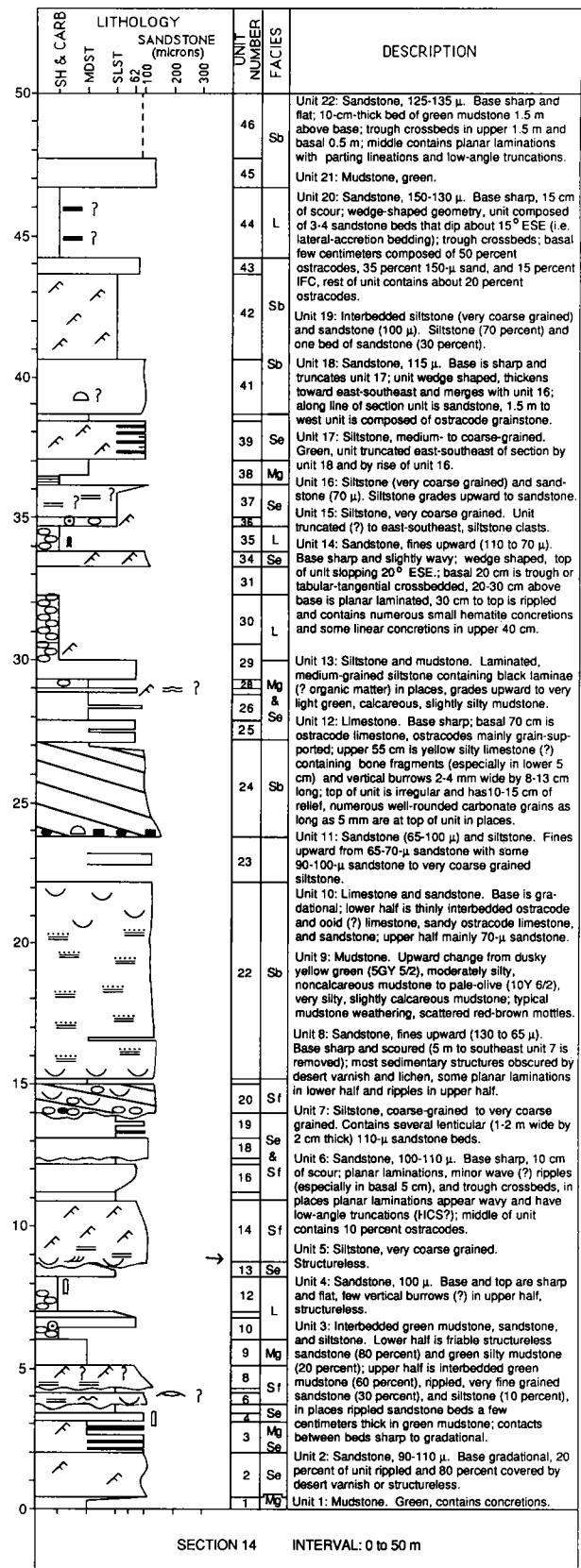
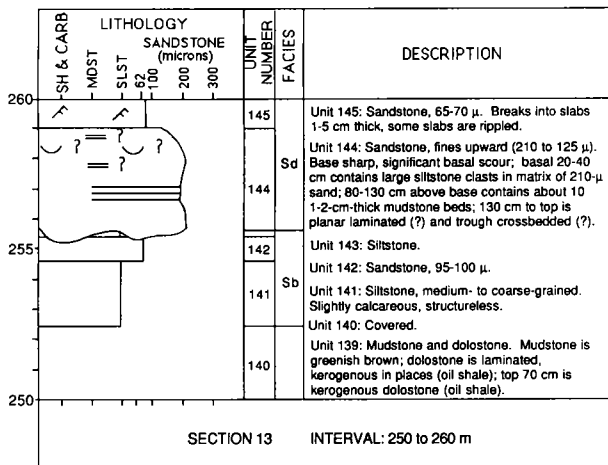


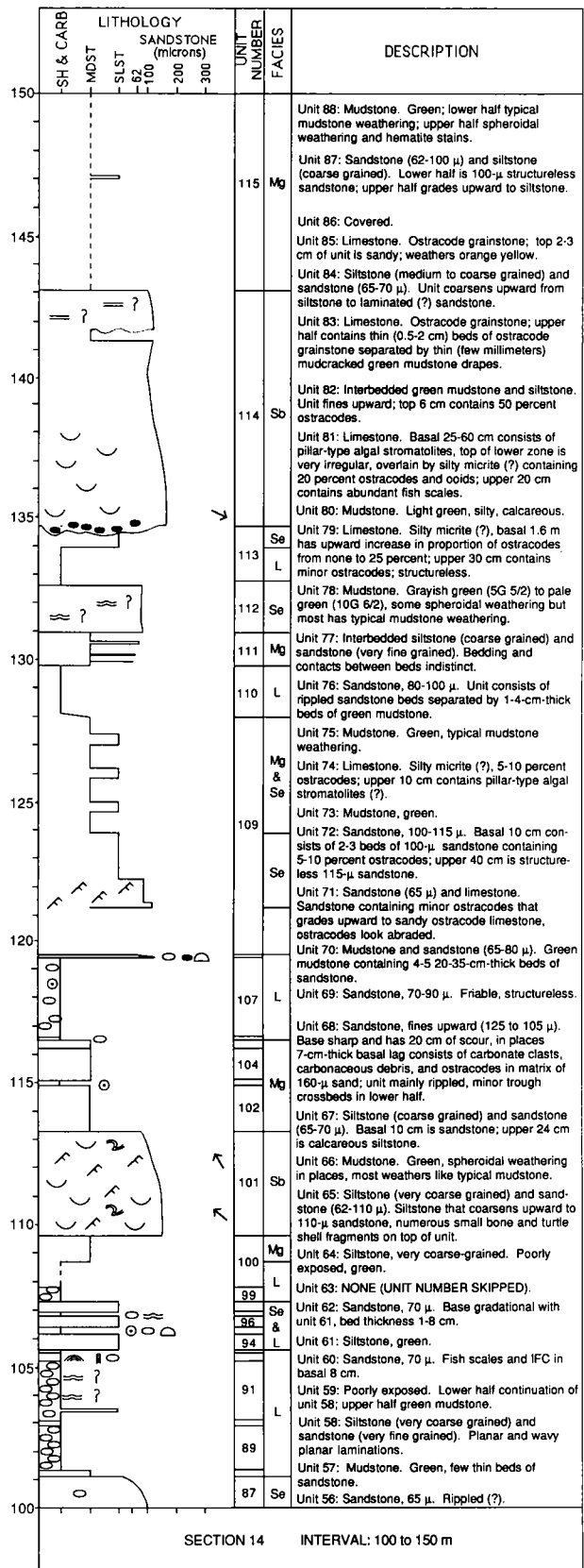
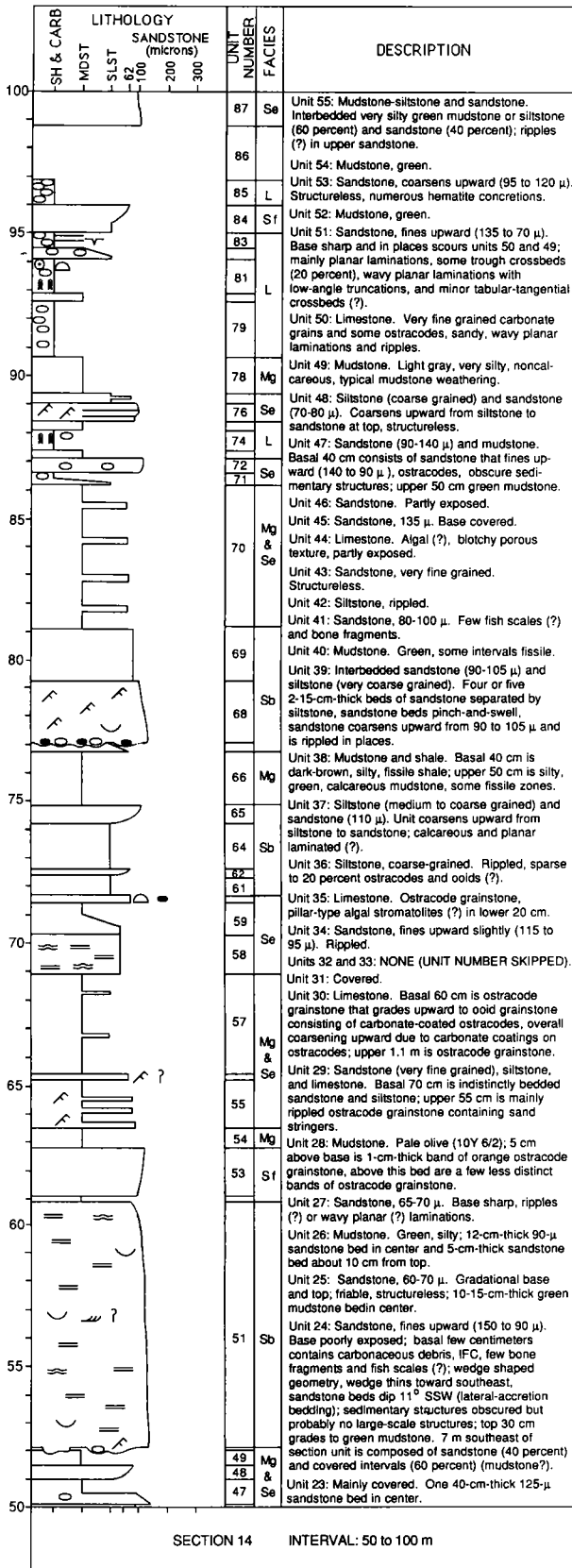


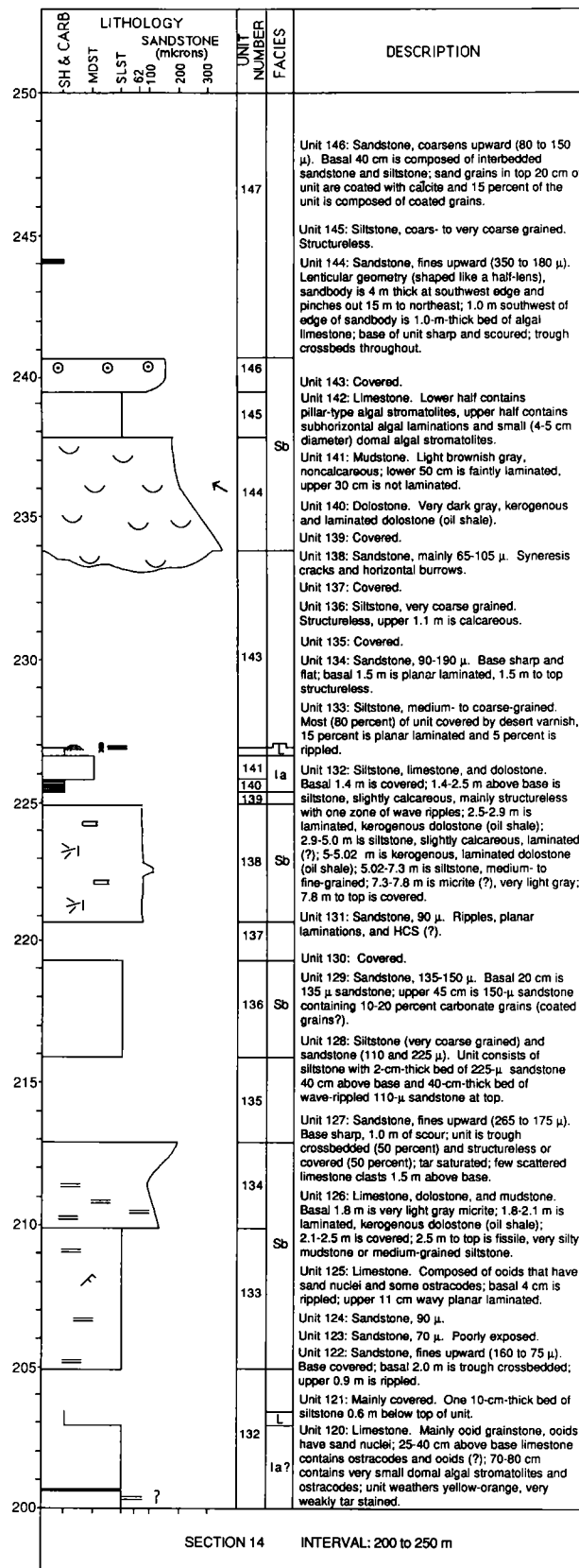
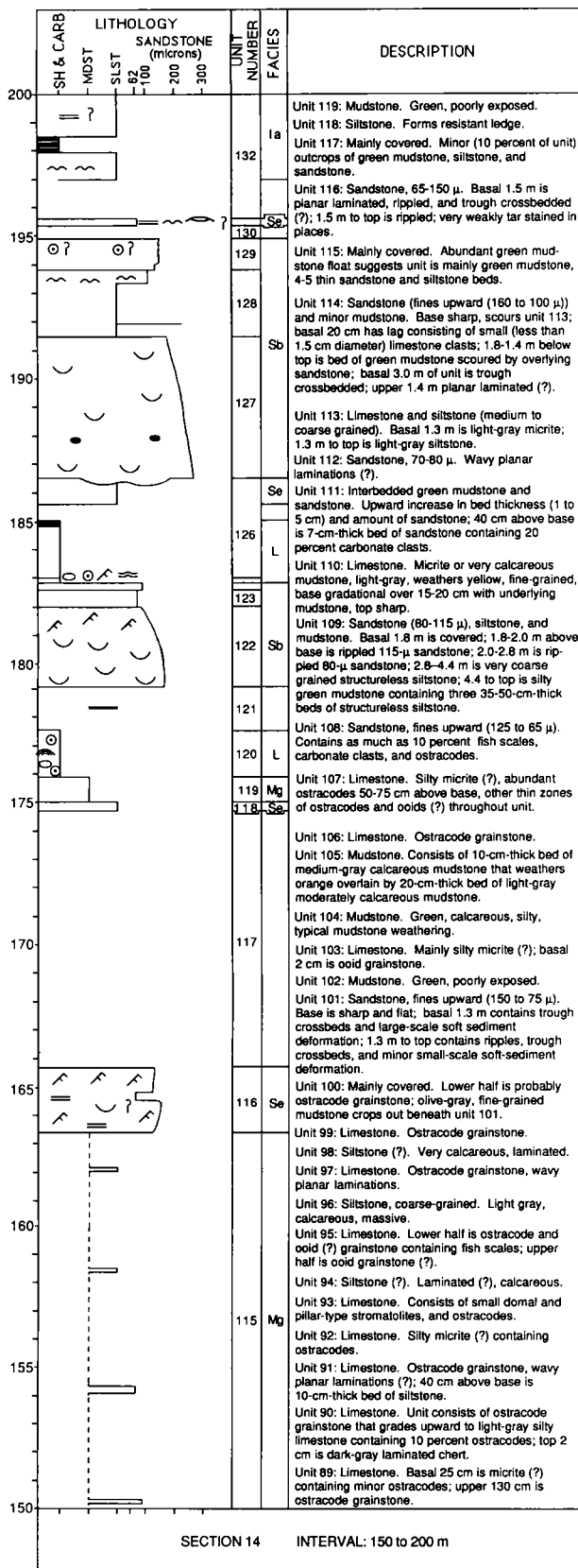


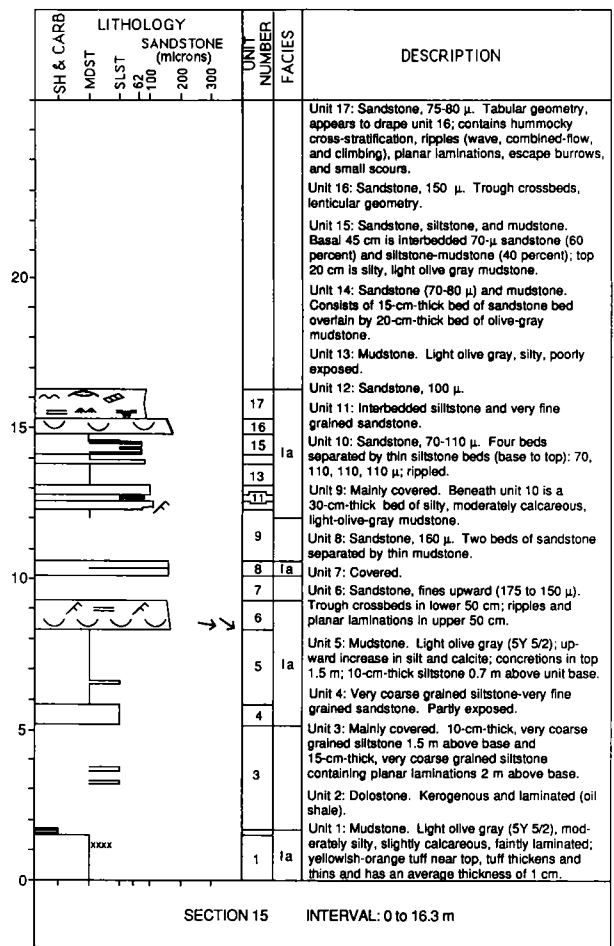
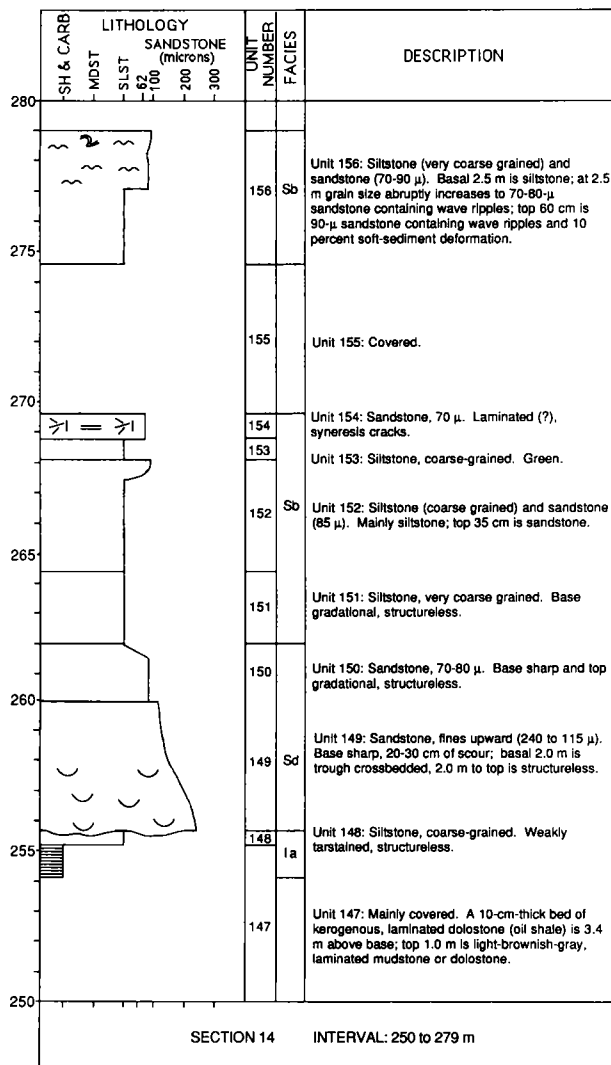


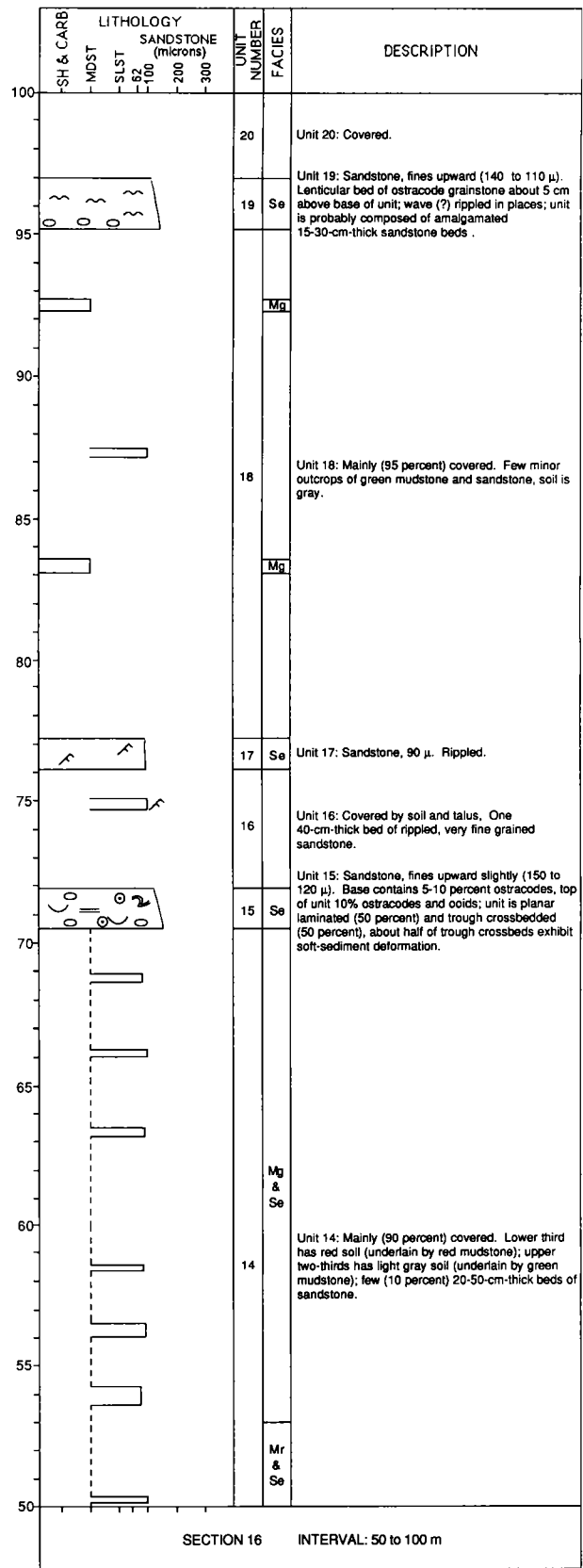
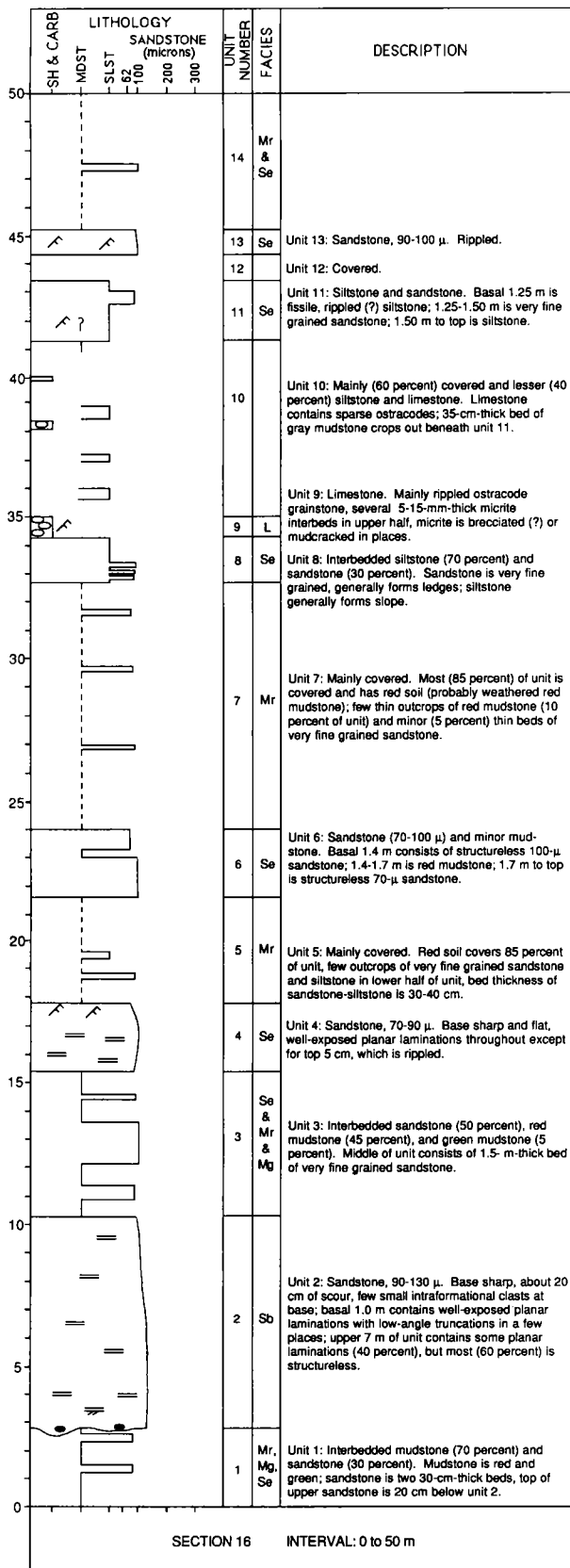


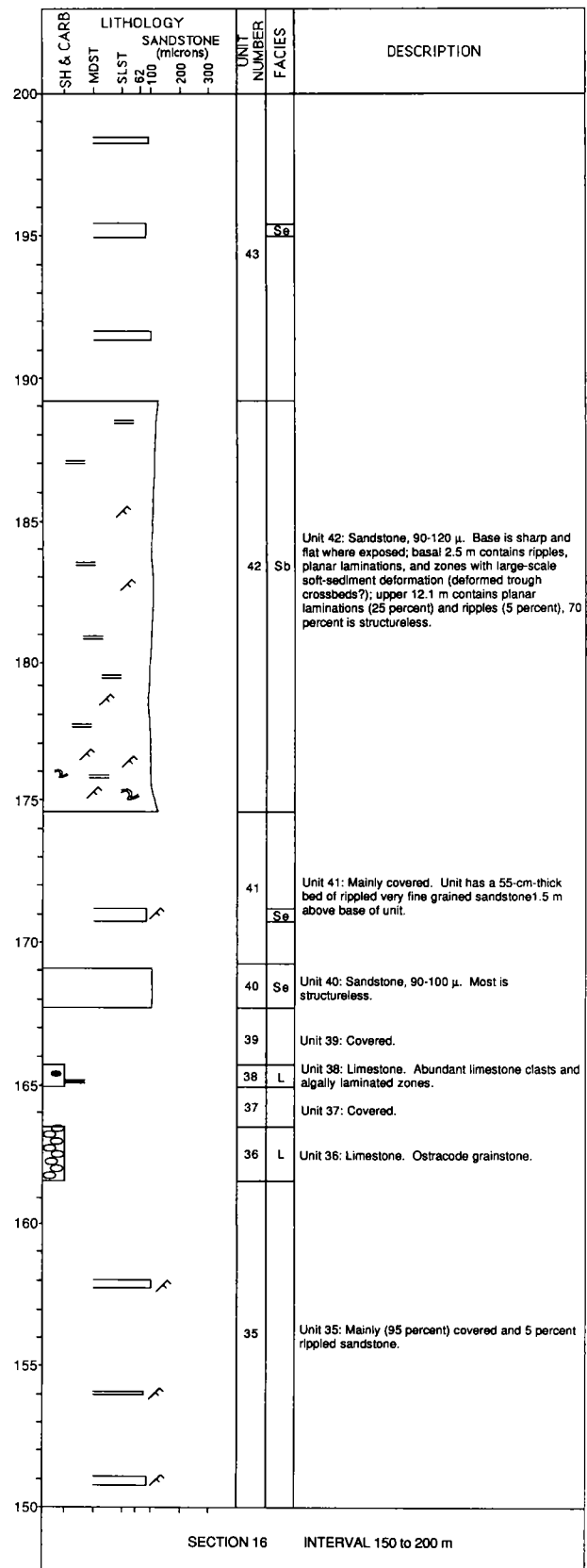
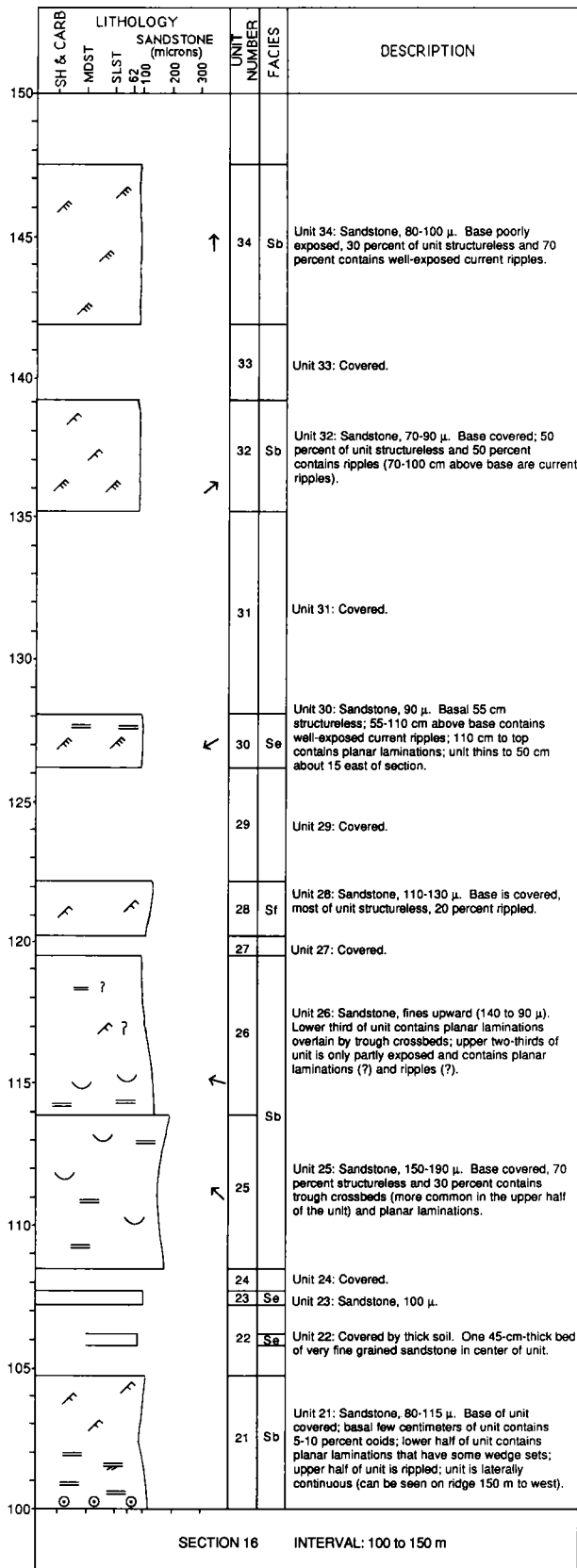


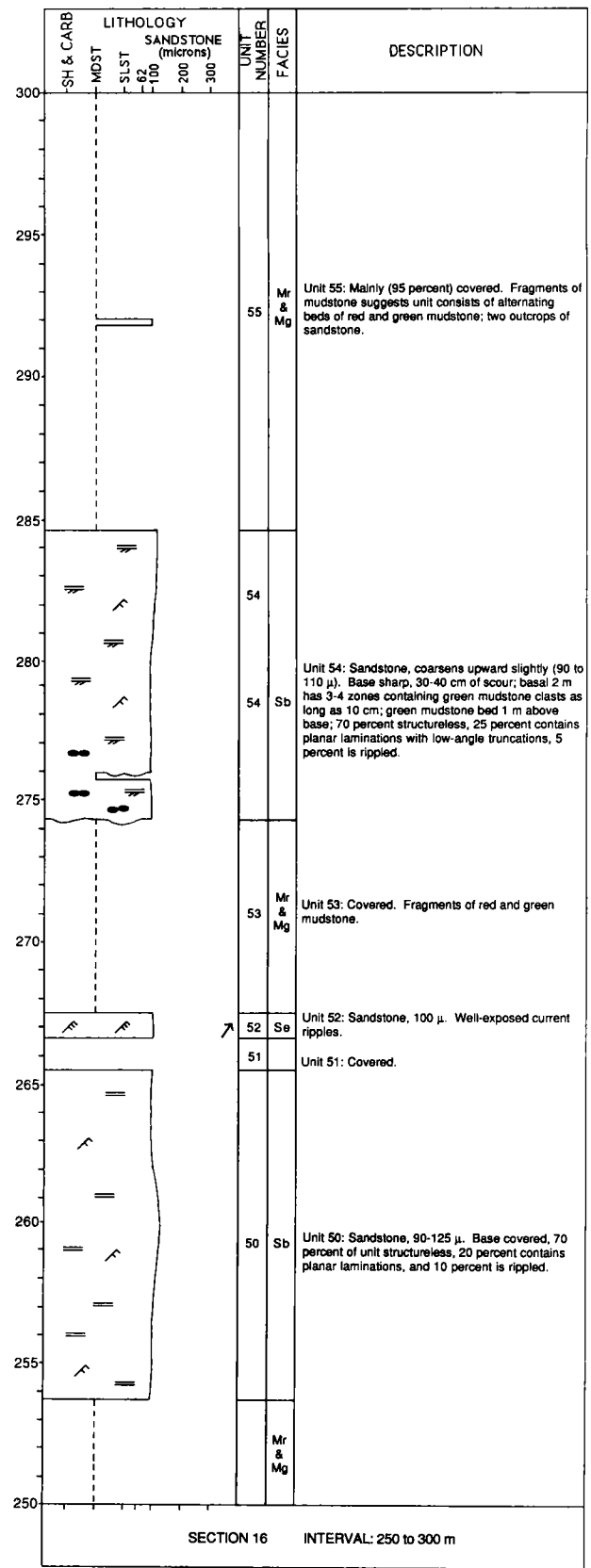
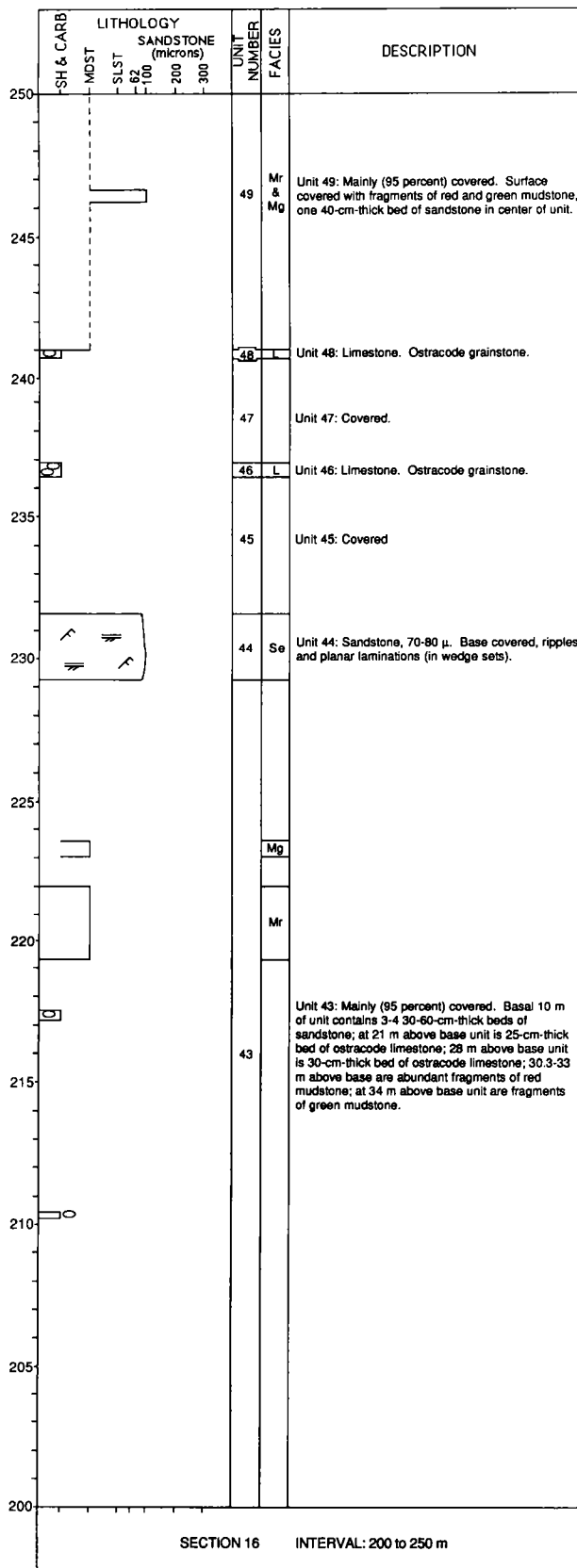




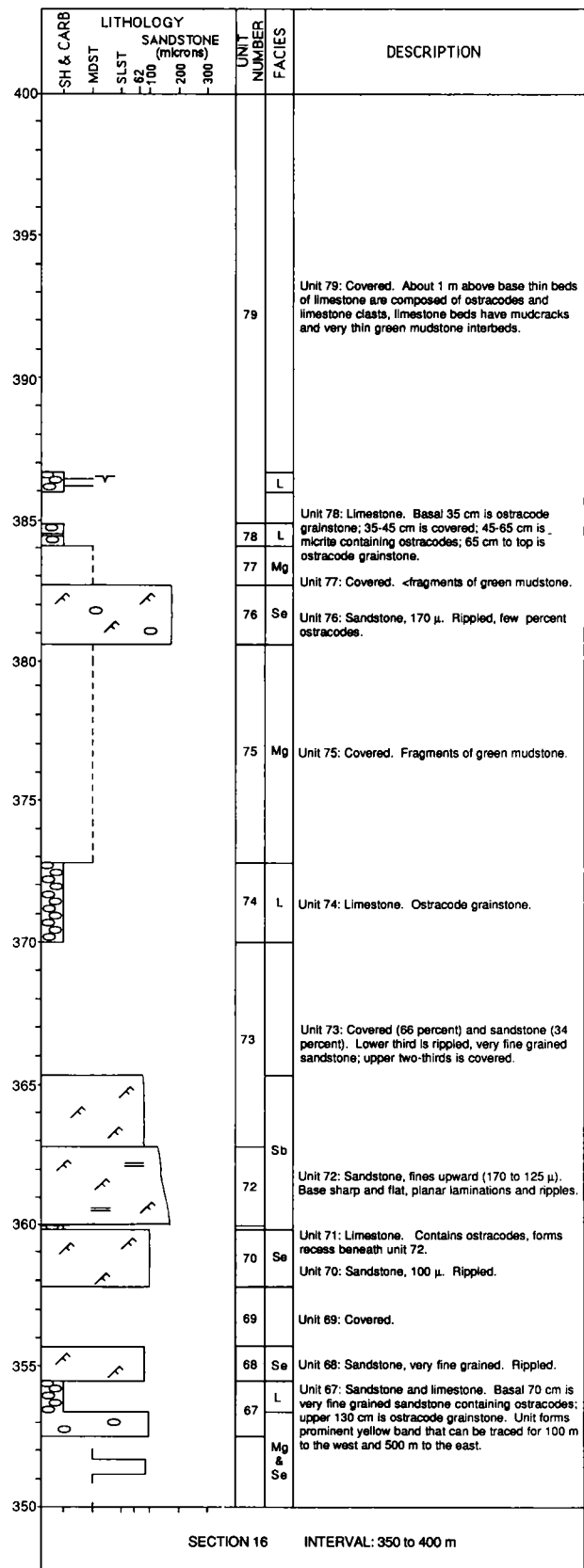
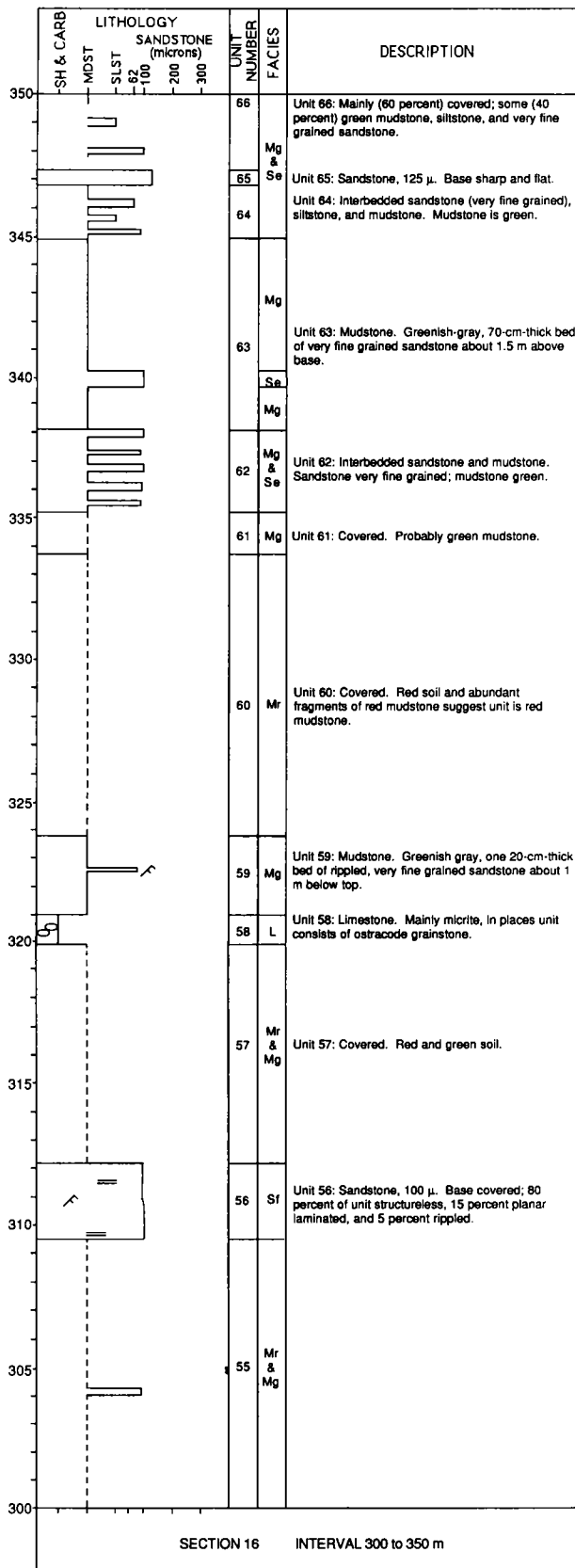


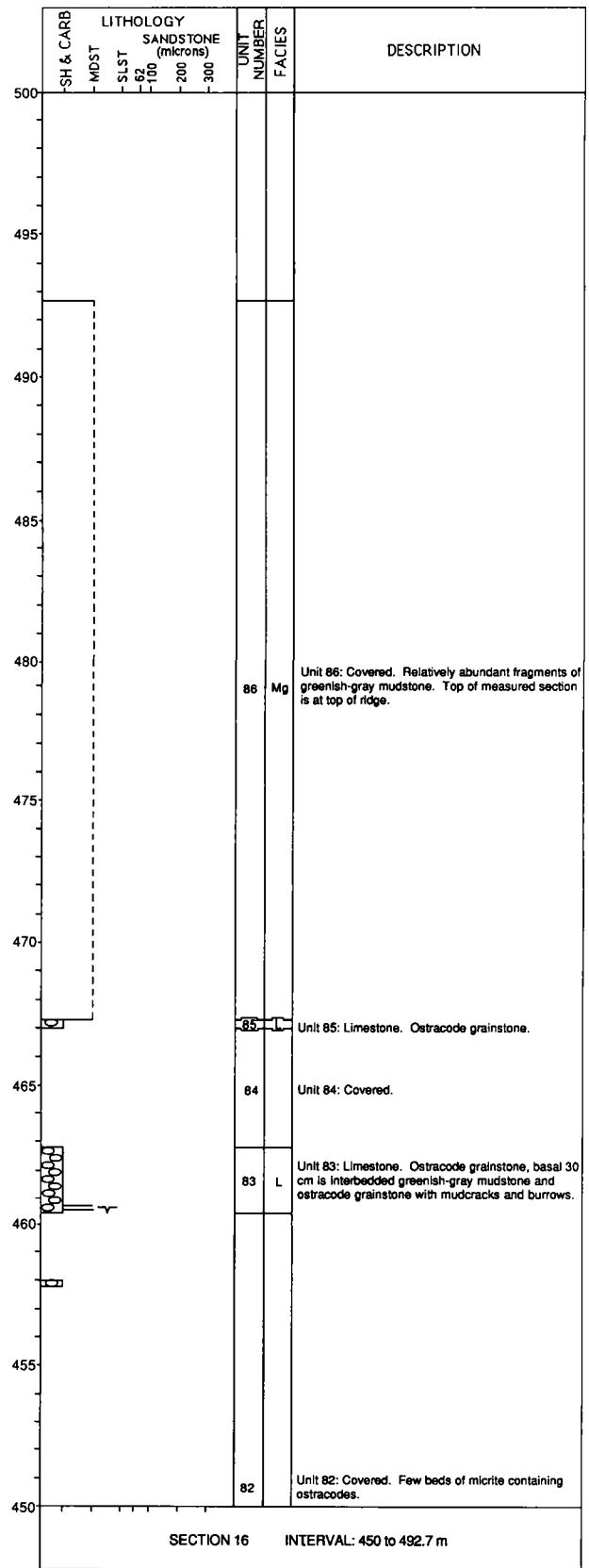
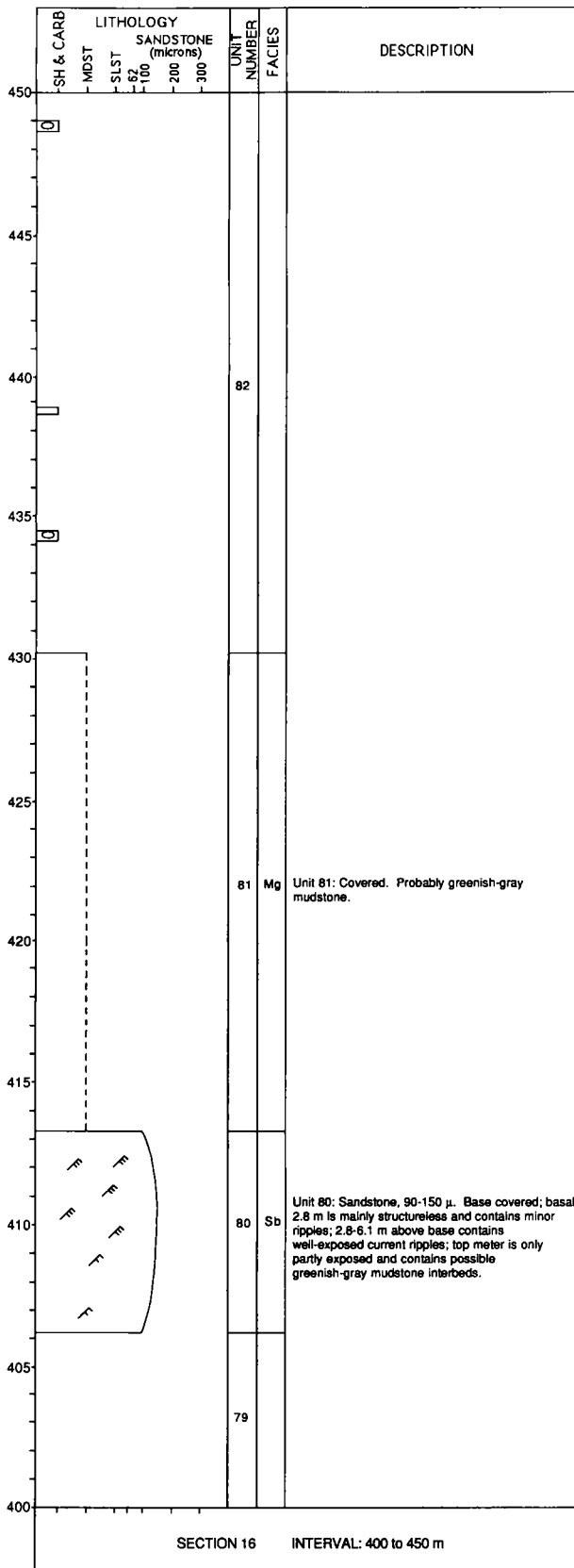


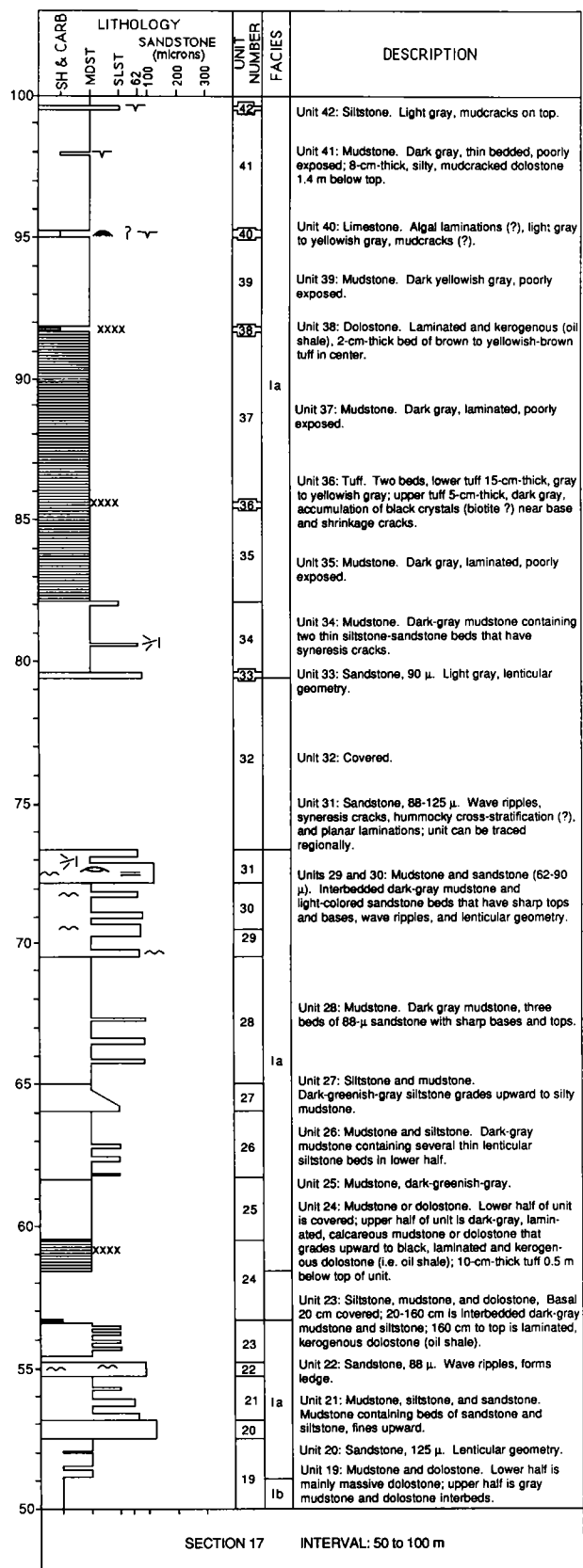
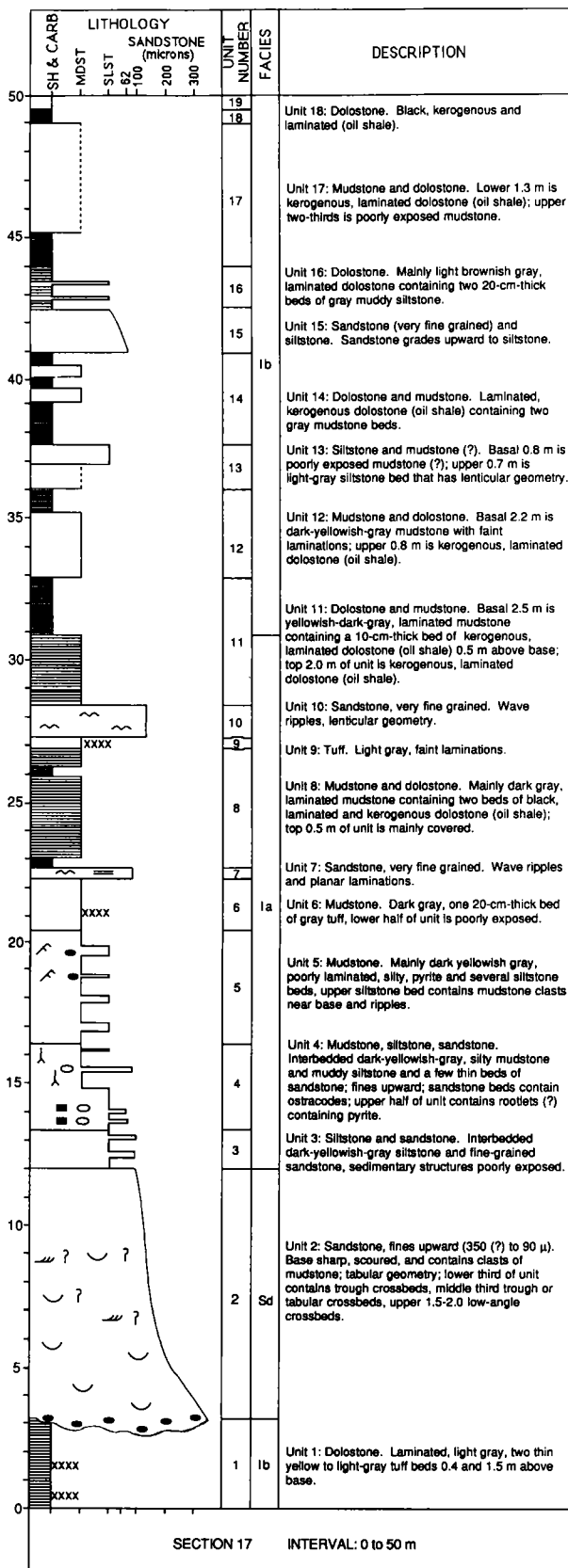


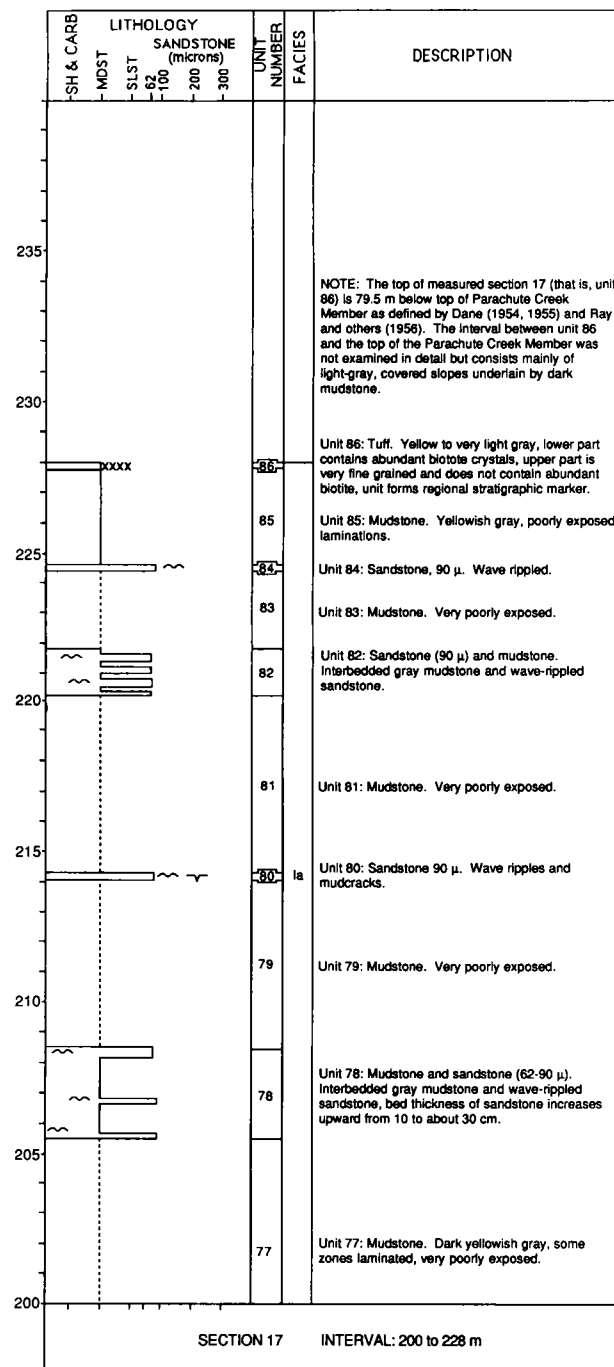
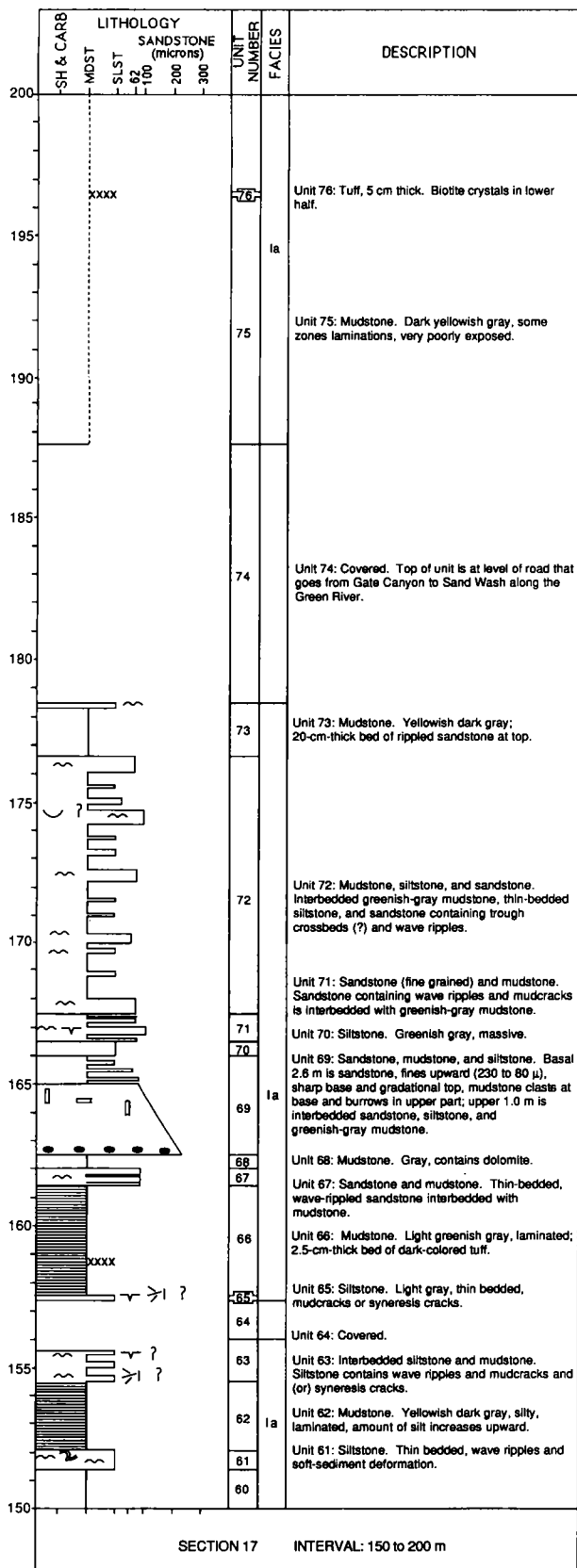


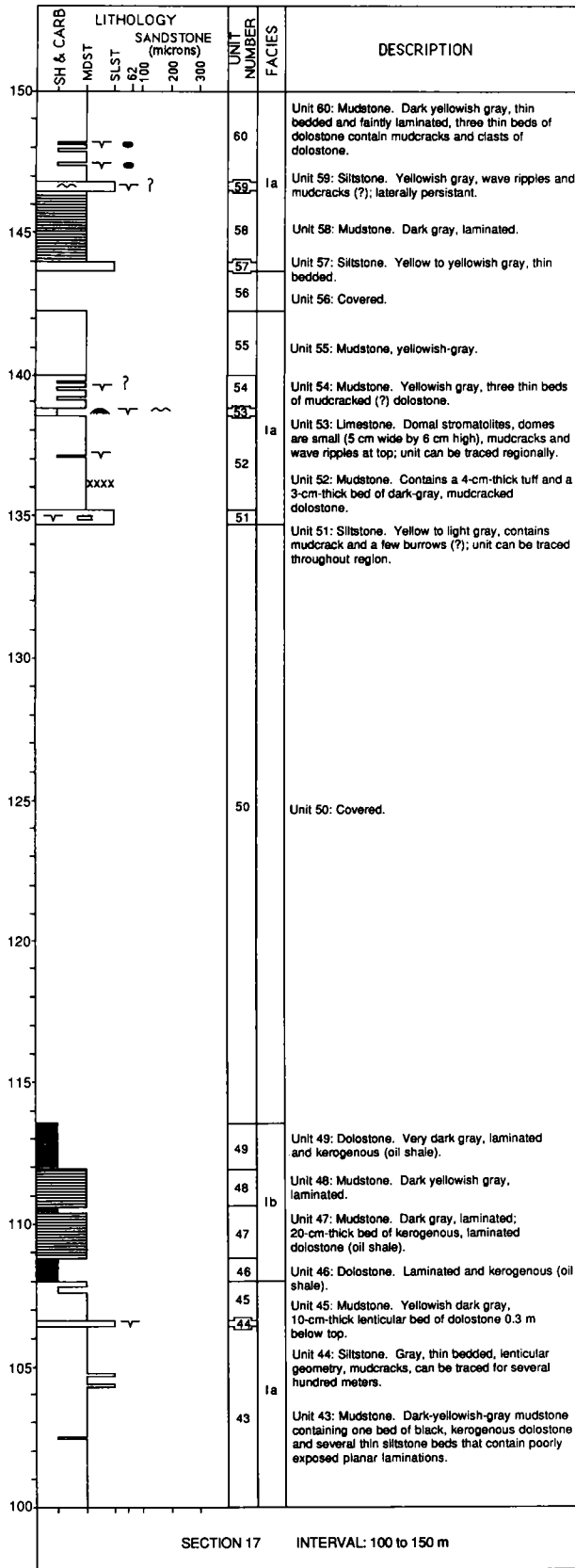








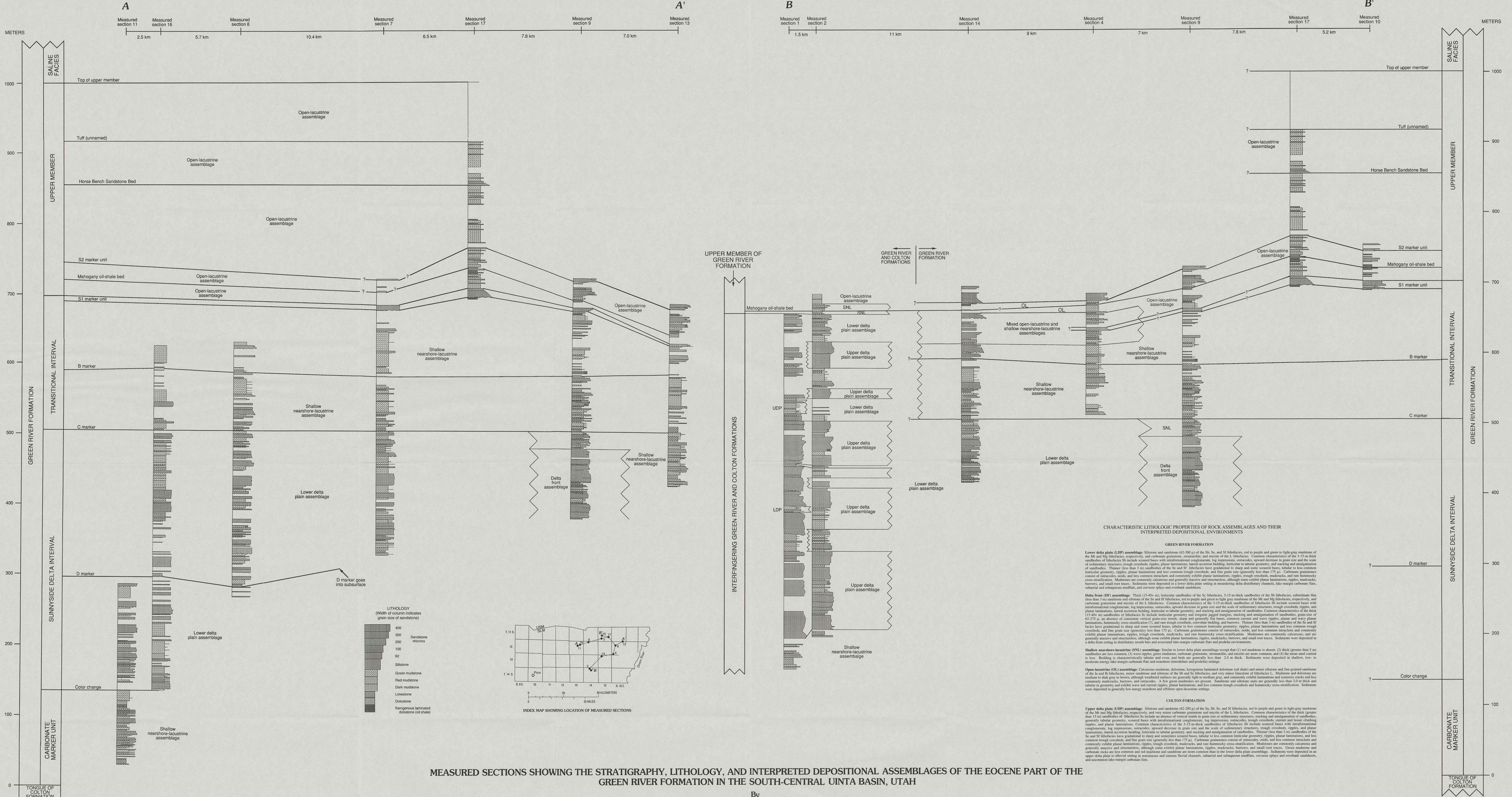




EXPLANATION

- Ripple, type unknown
- Wave ripple
- Current ripple
- Climbing ripple
- Combined-flow ripple
- Trough
- Tabular-planar crossbedding
- Tabular-tangential crossbedding
- Planar laminations in wedge sets
- Planar laminations
- Planar laminations with parting lineations
- Wavy planar laminations
- Sigmoidal crossbedding
- Hummocky cross-stratification (HCS)
- Mudcrack
- Syneresis crack
- Rootlet
- Burrow, vertical
- Burrow, horizontal
- Escape burrow
- Intraformational conglomerate (IFC)
- Poorly exposed interval
- Gastropod
- Pelecypod
- Ostracode
- Oncolite
- Wood impressions (trunks to twigs)
- Carbonaceous debris
- Oolite
- Fish scale
- Mud drape
- Stromatolite, domal
- Stromatolite, small pillars
- Stromatolite, subhorizontal laminations
- Convolute bedding
- Tuff layer or bed
- Identification unknown
- Herringbone cross-stratification
- Sharp, eroded basal contact
- Basal load cast
- Paleoflow (arrow points in direction of flow)
- Laminations (in dolostone, mudstone, or shale)
- Kerogenous laminated dolostone (oil shale)





MEASURED SECTIONS SHOWING THE STRATIGRAPHY, LITHOLOGY, AND INTERPRETED DEPOSITIONAL ASSEMBLAGES OF THE EOCENE PART OF THE GREEN RIVER FORMATION IN THE SOUTH-CENTRAL UINTA BASIN, UTAH

By  
Robert R. Remy  
1992

**CHARACTERISTIC LITHOLOGIC PROPERTIES OF ROCK ASSEMBLAGES AND THEIR INTERPRETED DEPOSITIONAL ENVIRONMENTS**

**GREEN RIVER FORMATION**

**Lower delta plain (LDP) assemblage:** Siltstone and sandstone (62-300  $\mu$ ) of the S<sub>1</sub>, S<sub>2</sub>, and S<sub>3</sub> lithofacies, red to purple and green to light-gray mudstone of the M<sub>1</sub> and M<sub>2</sub> lithofacies, respectively, and carbonate granitoid, stromatolite, and micrite of the L<sub>1</sub> lithofacies. Common characteristics of the 1-15-m-thick sandstones of lithofacies S<sub>1</sub> include scoured bases with interfacial conglomerate, log impressions, oolites, upward decrease in grain size and the scale of sedimentary structures, trough crossbeds, ripples, and planar laminations, lateral accretion bedding, lenticular to tabular geometry, and stacking and amalgamation of sandbodies. Thinner (less than 3 m) sandbodies of the S<sub>2</sub> and S<sub>3</sub> lithofacies have gradational to sharp and some scoured bases, tabular to less common lenticular geometry, ripple, planar laminations and less common trough crossbeds, and fine grain size (generally less than 175  $\mu$ ). Carbonate granitoid consists of oolites, siltstone, and less common structures and commonly exhibit planar laminations, ripples, trough crossbeds, mudcracks, and rare hummocky cross-stratification. Mudstones are commonly calcareous and generally massive and structureless, although some exhibit planar laminations, ripples, mudcracks, burrows, and small root traces. Sediments were deposited in a lower delta plain setting in meandering delta distributary channels, lake-margin carbonate flats, subaerial and subaqueous mudflats, and crevasse splays and oxbow channels.

**Delta front (DF) assemblage:** Thick (15-40 m), lenticular sandbodies of the S<sub>1</sub> lithofacies, 3-15-m-thick sandbodies of the S<sub>2</sub> lithofacies, subordinate thin (less than 3 m) sandstone and siltstone of the S<sub>3</sub> and S<sub>4</sub> lithofacies, red to purple and green to light-gray mudstone of the M<sub>1</sub> and M<sub>2</sub> lithofacies, respectively, and carbonate granitoid and micrite of the L<sub>1</sub> lithofacies. Common characteristics of the 3-15-m-thick sandbodies of lithofacies S<sub>1</sub> include scoured bases with interfacial conglomerate, log impressions, oolites, upward decrease in grain size and the scale of sedimentary structures, trough crossbeds, ripples, and planar laminations, lateral accretion bedding, lenticular to tabular geometry, and stacking and amalgamation of sandbodies. Common characteristics of the thick (15-40-m) sandbodies of lithofacies S<sub>2</sub> include lenticular geometry and irregular jagged margins, stacking and amalgamation of sandbodies, grain size of 62-275  $\mu$ , an absence of constant vertical grain-size trends, sharp and generally flat bases, common current and wave ripples, planar and wavy planar laminations, hummocky cross-stratification (?), and fine grain size (generally less than 175  $\mu$ ). Carbonate granitoid consists of oolites, siltstone, and less common structures and commonly exhibit planar laminations, ripples, trough crossbeds, mudcracks, and rare hummocky cross-stratification. Mudstones are commonly calcareous, and are generally massive and structureless, although some exhibit planar laminations, ripples, mudcracks, burrows, and small root traces. Sediments were deposited in a delta front setting in distributary, oxbow, and associated lake-margin carbonate flats and prodelta environments.

**Shallow nearshore-lacustrine (SNL) assemblage:** Similar to lower delta plain assemblage except that (1) red mudstone is absent, (2) thick (greater than 5 m) sandbodies are less common, (3) wave ripples, green mudstone, carbonate granitoid, stromatolite, and micrite are more common, and (4) the mean sand content is low. Bedding is characteristically tabular and even, and beds are generally less than 2.0 m thick. Sediments were deposited in shallow, low-to moderate-energy lake-margin carbonate flats and nearshore (intertidal and prodelta) settings.

**Open-lacustrine (OL) assemblage:** Calcareous mudstone, dolomite, lenticular laminated dolomite (oil shale) and minor siltstone and fine-grained sandstone of the L<sub>1</sub> and L<sub>2</sub> lithofacies, very fine-grained carbonate granitoid and micrite of the L<sub>1</sub> lithofacies, and very minor limestone of lithofacies L<sub>2</sub>. Mudstone and dolomite are medium to dark gray to brown, although weathered surfaces are generally light to medium gray, and commonly exhibit laminations and systems cracks and less commonly mudcracks, burrows, and oolites. A few green mudstones are present. Sandstone and calcareous units are generally less than 2.0 m thick and tabular in geometry and exhibit wave and current ripples, planar laminations, and less common trough crossbeds and hummocky cross-stratification. Sediments were deposited in generally low energy nearshore and offshore open-lacustrine settings.

**COLTON FORMATION**

**Upper delta plain (UDP) assemblage:** Siltstone and sandstone (62-280  $\mu$ ) of the S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>, and S<sub>4</sub> lithofacies, red to purple and green to light-gray mudstone of the M<sub>1</sub> and M<sub>2</sub> lithofacies, respectively, and carbonate granitoid and micrite of the L<sub>1</sub> lithofacies. Common characteristics of the 3-15-m-thick sandstones of lithofacies S<sub>1</sub> include scoured bases with interfacial conglomerate, log impressions, oolites, upward decrease in grain size and the scale of sedimentary structures, trough crossbeds, ripples, and planar laminations, lateral accretion bedding, lenticular to tabular geometry, and stacking and amalgamation of sandbodies. Thinner (less than 3 m) sandbodies of the S<sub>2</sub> and S<sub>3</sub> lithofacies have gradational to sharp and some scoured bases, tabular to less common lenticular geometry, ripple, planar laminations, and less common trough crossbeds, and fine grain size (generally less than 175  $\mu$ ). Carbonate granitoid consists of oolites, siltstone, and less common structures and commonly exhibit planar laminations, ripples, trough crossbeds, mudcracks, and rare hummocky cross-stratification. Mudstones are commonly calcareous and generally massive and structureless, although some exhibit planar laminations, ripples, mudcracks, burrows, and small root traces. Green mudstone and carbonate rocks are less common and red mudstone and sandstone are more common than in the lower delta plain assemblage. Sediments were deposited in an upper delta plain to alluvial setting in meandering distributary channels, subaerial and subaqueous mudflats, crevasse splays and oxbow channels, and uncommon lake-margin carbonate flats.

Detailed descriptions of measured sections are given in appendix. Definition of lithofacies given in table 1. Stratigraphic interpretation of Robert R. Remy, 1991.

