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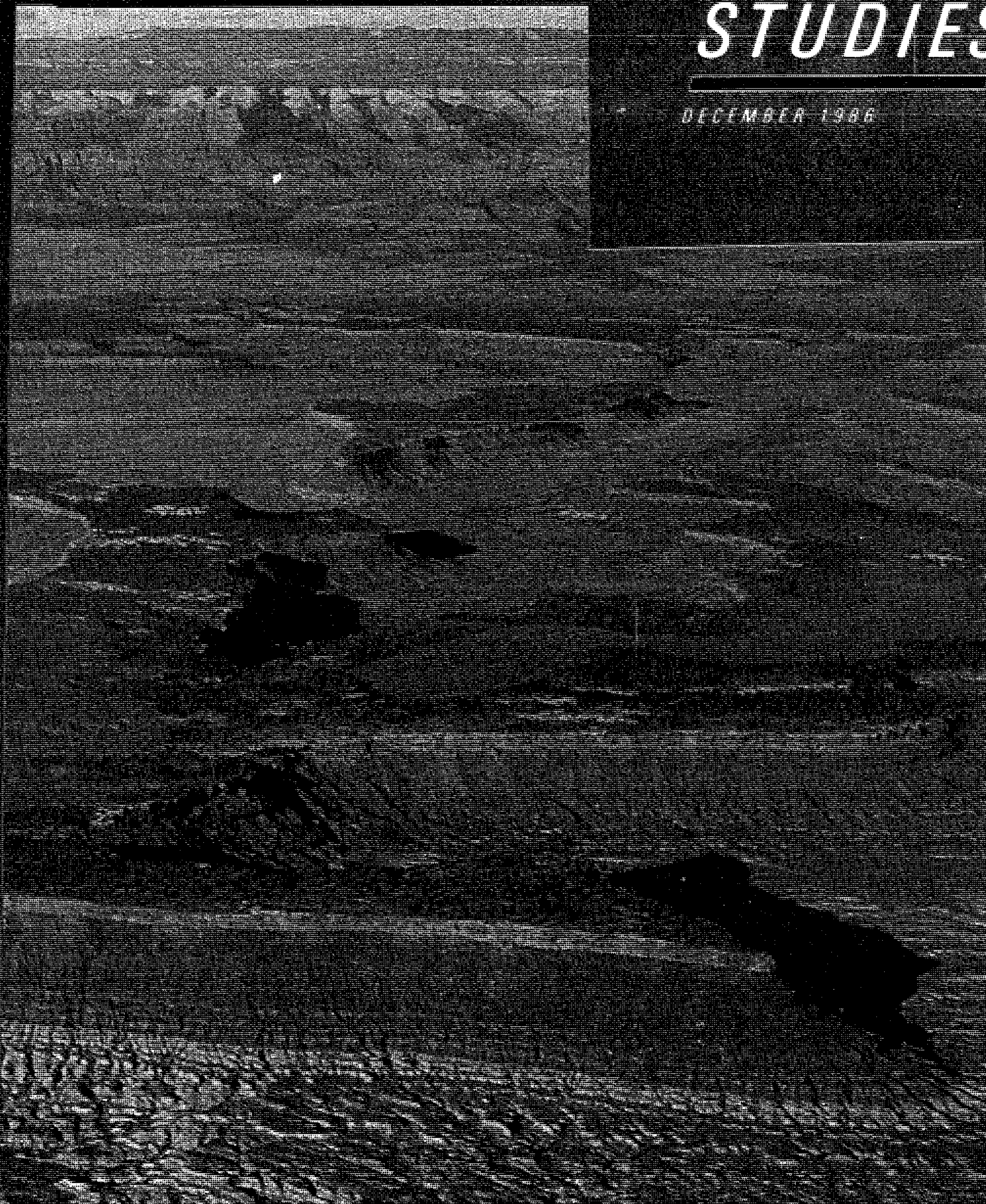

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THE GLORY OF GOD IS INTELLIGENCE

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Depositional Environments of the Tertiary Colton and Basal Green River Formations in Emma Park, Utah*

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ABSTRACT

Thick, spectacularly exposed sandstone ledges and laterally continuous limestone ledges of the Colton and basal Green River Formations in Emma Park, Utah, provide an excellent opportunity for study of the depositional environment of the transition zone between deltaic-fluvial and lacustrine environments. During late Paleocene to early Eocene, Colton deltaic deposits encroached into the Flagstaff basin from the south and southeast. Lenticular point bar sandstone deposits and overbank sheet deposits of sandstone and siltstone are enclosed within bioturbated red mudstone deposits of the flood basin. A sequence of thick, multistory sandstone lenses in the upper half of the Colton indicate a period of fluvial plain deposition. Avulsion of the principle Colton stream introduced a destructional deltaic environment. Deltaic deposition decreased, and dewatering and compaction of the deltaic deposits allowed transgression of a lacustrine shoreline environment onto the delta plain. Deposition of gray-hued lacustrine limestones and shales became dominant, and ostracods and mollusks abounded in the shallow shoreline environment. The color change from red to gray is a principle characteristic of the Colton–Green River contact in Emma Park. In detail this contact is seen to be a zone of clastic deltaic deposits interfingering with clastic and chemical lacustrine deposits. Short- and long-period fluctuations of the lake's water level; wind-driven seiches, waves, and currents; climate; basin gradient, configuration, and tectonics; stream flow regime and sediment load; stream avulsion; and stream and lake water interaction were all important in forming the transitional deltaic to lacustrine facies seen in Emma Park. Tongues of deltaic rocks exist above and below the main body of Colton deposition. Projection of the depositional model into three dimensions indicates the potential for sandstone oil and gas reservoirs in the subsurface to the north and northwest of Emma Park.

INTRODUCTION

Thick, spectacularly exposed sandstone lenses and laterally continuous limestone ledges of the Colton and Green River Formations in Emma Park, Utah, provide an excellent example for study of the depositional environment of the transition zone between deltaic-fluvial and lacustrine environments. In addition, Colton sandstone lenses are potential oil and gas reservoirs in the subsurface to the north and northwest. The Paleocene–lower Eocene Colton Formation contains numerous lenses of light gray to pale red ledge-forming sandstone that are thicker and more extensive in Emma Park than in Colton outcrops to the west.

The Colton Formation was deposited in a fluvial, freshwater deltaic environment (Moussa 1965; Peterson 1976). These strata or their equivalents underlie much of the Uinta Basin to the north (Fouch 1975) and parts of the Wasatch Plateau to the west and southwest of Emma Park (Mercantel and Weiss 1968). The overlying Green River Formation and the underlying Flagstaff Formation are of lacustrine origin (Spieker 1946) and limestone is the dominant lithology near their respective contacts with the Colton Formation.

There are no published detailed descriptions of the contact zone between the Colton and Green River For-

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mations. This investigation has been made, in part, to document the stratigraphy of this zone and to provide material for an interpretation of the depositional environments of this section of rocks. The direction of sediment transport and the geometry of the sandstone lenses have also been used to construct a three dimensional model of the sandstone bodies. These data and interpretations have been used to evaluate the potential for oil and gas reservoirs in the Colton Formation in the subsurface north of Emma Park.

LOCATION AND ACCESS

The Colton Formation crops out along the boundary between the Wasatch Plateau and the Tavaputs Plateau, on the southwest flank of the Uinta Basin. The Colton Formation has been eroded to form a strike valley that extends eastward from near the townsite of Tucker, west of Soldier Summit in Utah County, to Whitmore Canyon, near Sunnyside, in Carbon County. The strike valley broadens eastward from Soldier Summit to Brook Meadow, which is approximately 7 km east of Utah 33. The part of the valley between Kyune, at the head of Price Canyon, and Brook Meadow is called Emma Park. East of Emma Park the Roan and Book Cliffs converge and the Colton valley narrows rapidly.

U.S. 6-50 follows the Colton valley from near the townsite of Tucker eastward to the head of Price Canyon, near the junction at Kyune. That highway then turns southward and parallels the Price River down the canyon toward Helper and Price. A paved county road leaves U.S. Highway 6-50 at Kyune, crosses the Price River, and continues eastward through Emma Park to a junction with Utah 33 near Willow Creek (fig. 1). Most of the outcrops studied for this report are readily accessible from the county road. The others in the canyon of the West Fork of Willow Creek can be reached by a sideroad from Utah 33, about 3.5 km north of the junction with the Emma Park county road. Unpaved roads, with locked gates, lead north from the county road across the property of James T., Jerry L., and Dix Jensen of Price, Utah. These roads cross the valley bottom, where numerous wet meadows, seeps, and springs make travel off the paved road difficult, except during late summer and autumn.

This study includes that part of Emma Park between Utah 33 and the Utah County–Duchesne County line, including all or parts of sections 21, 22, 27–34, of T. 11 S, R. 10 E (SLM), in Duchesne County and sections 3–10 of T. 12 S, R. 10 E (SLM) in Carbon County, Utah (fig. 2). One stratigraphic section was measured several kilometers to the west of this area near Kyune railroad siding. The base of that section is in section 32, and the traverse goes north through section 29 into the SE 1/4 of section 20, all in T. 11 S, R. 9 E (SLM), in Utah County, Utah.

PREVIOUS WORK

The Colton Formation or equivalent rocks belong to the "Wasatch group" described by Hayden (1869) in exposures west of Fort Bridger, Wyoming.

The Emma Park area and Colton strata were included in several early regional studies, starting with E. E. Howell's (1875) description of the geology of the Wasatch Plateau and adjacent areas, and C. E. Dutton's (1880) account of the geology of the high plateaus of Utah, including the Wasatch Plateau. Spieker and Reeside (1925) gave a generalized description of the stratigraphy of the Wasatch Plateau, including beds equivalent to the Colton Formation.

E. M. Spieker (1946) outlined the late Mesozoic and early Cenozoic history of the region, and formally proposed the Colton Formation for the exposures near Colton, Utah. These rocks were previously called the Upper Member of the Wasatch Formation. Spieker also noted the intertonguing of the Colton Formation with the Green River and Flagstaff Formations and concluded that the Colton is equivalent, in age, with the lower part of the Green River Formation in exposures to the west.

Henderson (1958) studied the general geology and mapped the northeast quarter of the Soldier Summit Quadrangle, which includes the type outcrop of the Colton Formation. Prescott (1958) mapped the northwest quarter of the Soldier Summit Quadrangle and documented the westward pinchout of the Colton beds into the Green River Formation. Moussa (1965) mapped the entire Soldier Summit Quadrangle. His report included a discussion of the Colton–Green River boundary problem

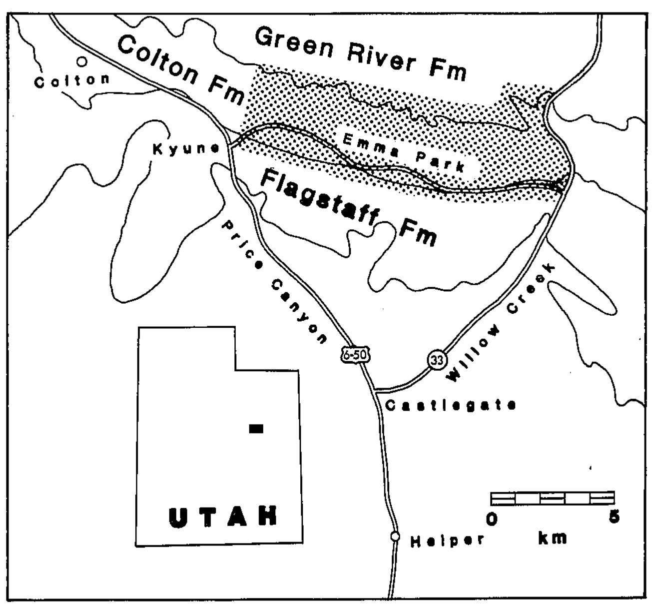

FIGURE 1.—*Index map, location of study area shaded.*

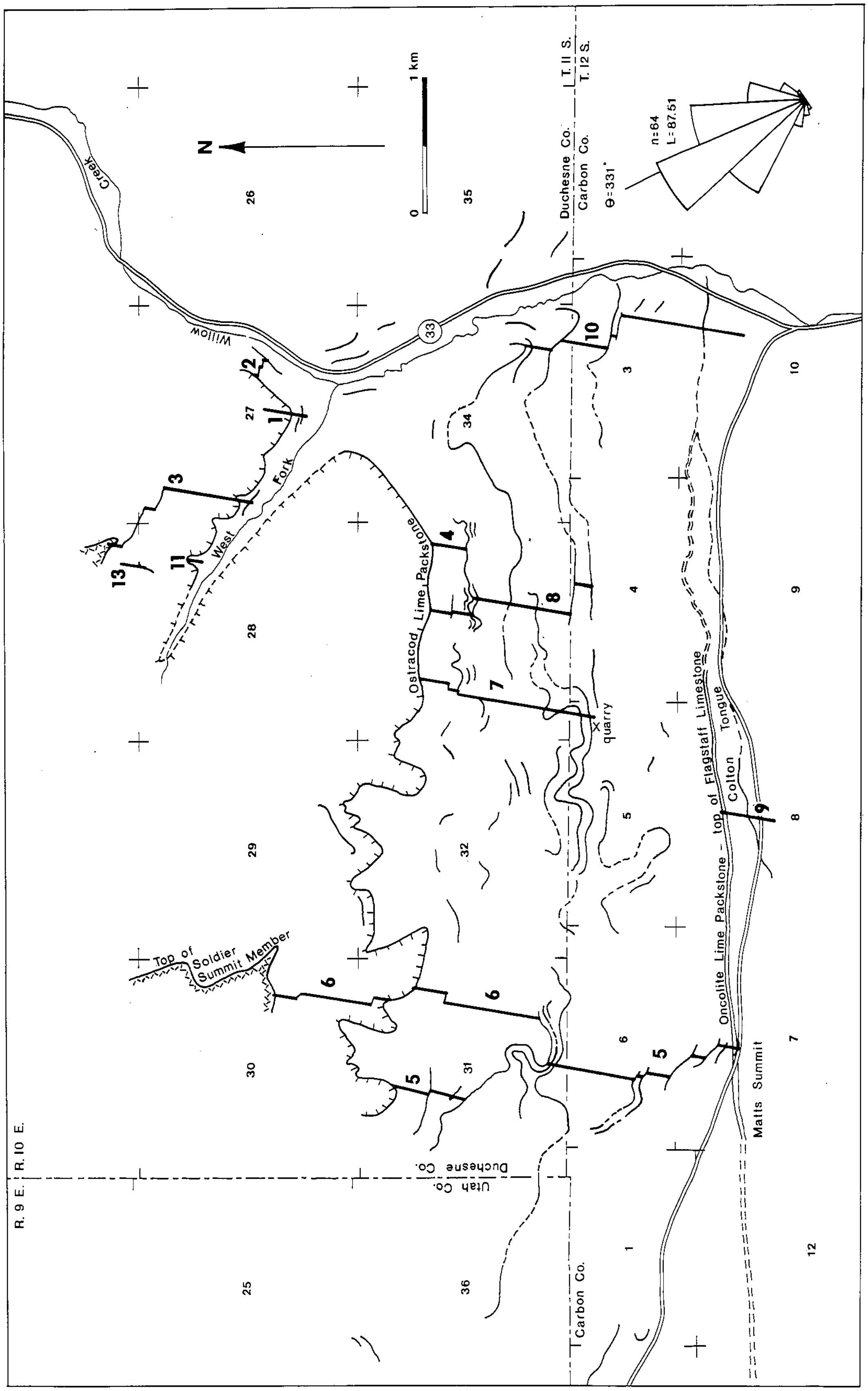

FIGURE 2.—*Map showing locations of measured sections 1–11 and 13. Major sandstone outcrops are shown by solid lines. Measured section 12 is several kilometers to west, at Kyune. Rose diagram shows sediment transport directions.*

and three measured sections which cover all or parts of the Colton Formation.

Peterson (1976) made a detailed study of the lower half of the Colton Formation between the type area, at Colton, and the head of Price Canyon, near Kyune. His work concentrated in the area west of the present study. Peterson made an environmental interpretation based on measured sections and microscopic and macroscopic examination of samples and sedimentary structures in outcrop and in roadcut exposures. He also described ichnofossils and plant remains he found in the Colton Formation.

Fossils are less abundant in the Colton Formation than in the enclosing lacustrine deposits, but La Rocque (1956, 1960) and Hamilton (1955) have described fossil mollusks from both the Colton and the lacustrine beds. Swain (1956) has described fossil ostrascods from Colton and Green River deposits. Bird fossils have been identified from the Colton Formation by Hardy (1959). Peck and Reker (1948) described charophytes taken from limestones and shales along Willow Creek, just below Colton red beds. Newman (1974) did a preliminary study of palynomorphs of the Tertiary rocks of the western Uinta Basin and areas in Colorado, and correlated the Colton Formation with the Douglas Creek Member of the Green River Formation on the Douglas Creek Arch in Colorado and with the central part of the Wasatch Formation in the Piceance Creek Basin of Colorado.

Roberts (1964) and Picard (1955) investigated the subsurface extent of the Green River Formation, including delineation of the boundary between the Green River and Colton Formations. Fouch (1975) and Ryder and others (1976) did more extensive studies of the Tertiary rocks in the subsurface of the Uinta Basin.

Numerous studies have been made of ancient and modern deltaic, fluvial, and lacustrine systems and their sedimentary features. Those which have been most useful in this present study are Fisher and Brown (1972), Coleman (1981), Ferm (1974), Gould (1970), Fisk and others (1954), Allen (1965a), Visher (1965), and Potter (1967). Of special note is a paper by Hyne and others (1979) on the lacustrine delta of the Catatumbo River in Lake Maracaibo, Venezuela.

METHODS OF STUDY

Field Methods

Thirteen stratigraphic sections (fig. 2 and plate 1, in pocket) were measured using a Jacob staff and a Brunton compass (Smith 1984). A cross section based on these measured sections is shown in plate 1. Units were differentiated according to lithologies. Samples were taken of major units of the measured sections for more extensive laboratory analysis. Sedimentary structures were noted and described in the field. Paleocurrent directions for each unit were determined where possible. Colors were identified using the rock-color chart (Goddard and others 1970) distributed by the Geological Society of America. Dips in the area range from 4° to 8° generally toward N 10° E.

High-altitude vertical aerial photographs, low-angle oblique aerial photographs, and detailed photographs taken on the ground were used to supplement fieldwork in correlation and description of the lithologic units.

Laboratory Methods

Thin sections were made of most limestone units, from representative sandstone lenses, and from one siltstone. Billets also were cut and polished from sandstone and siltstone samples. Clastic rock samples were impregnated with epoxy resin because of their friable nature. Sandstone billets and thin sections were stained for feldspar identification following the techniques of Bailey and Stevens (1960). Small areas on sandstone and limestone thin sections were stained for carbonate identification using methods described by Friedman (1959). Thin sections and billets were examined microscopically to determine composition, fabric, and fossil content. Three sandstone samples were prepared in polished billets and examined by reflected light microscopy for opaque mineral identification.

Sandstones were disaggregated, sieved on a Rotap shaker, and the size fractions weighed. Other sandstone and siltstone samples were disaggregated in dilute HCl to determine insoluble residues. A sample of channel-lag sandstone was disaggregated in dilute acetic acid to attempt recovery of vertebrate fossils.

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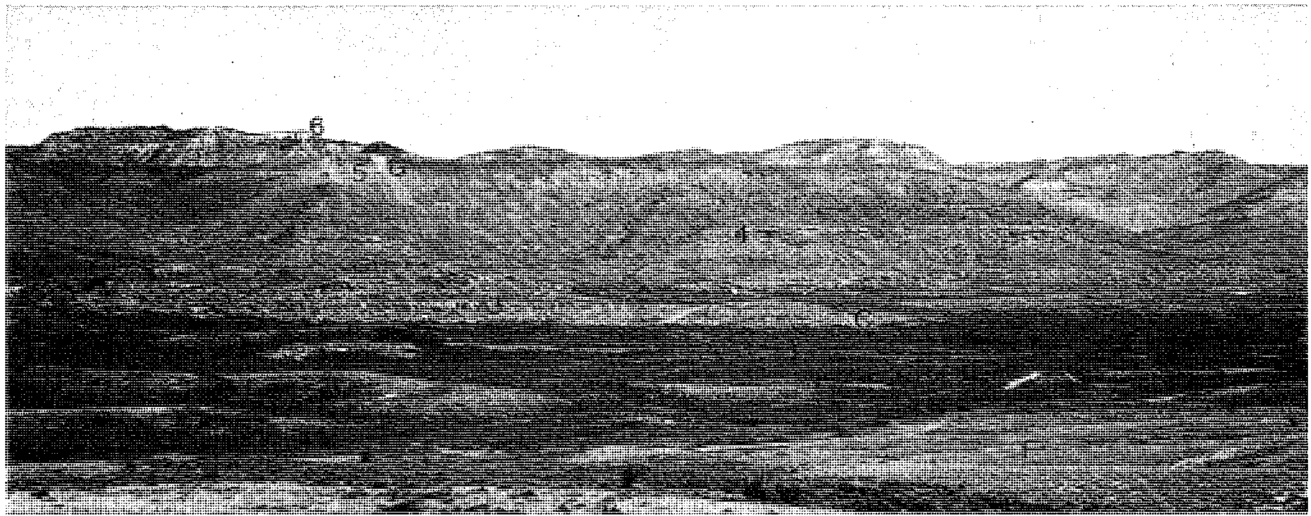

FIGURE 3.—*View north across Emma Park. Large multistoried sandstone bodies on slopes in upper Colton Formation, smaller single-storied sandstone lenses near valley floor of red mudstone. G—Green River Formation; C—Colton Formation; F—Flagstaff Formation; 1—oncolite-bearing lime packstone-wackestone; 2—dominantly fluvial overbank deposits of basal Colton Formation; 3—single-story point-bar sandstone, quarry is seen to left of numeral; 4—multistoried sandstone lense of upper Colton; 5—ostracod lime packstone; 6—top of Soldier Summit Member of Green River Formation.*

LITHOLOGIES

SANDSTONE

Sandstone forms the numerous ledges that, along with interbedded red mudstones, distinguish the Colton Formation in Emma Park (fig. 3). Sandstone is uniformly fine grained and very well sorted throughout the section (fig. 4). It occurs in both tabular sheets and thick composite bodies that have a lenticular shape in vertical cross section.

The sandstone of the Colton Formation generally has a pale red weathered color, but some beds are also light red, light greenish gray, yellowish gray, and shades of light brown. Freshly exposed surfaces are generally light gray to light greenish gray. Several sandstone units, such as unit 7 of measured section 2, are anomalously yellowish brown on fresh exposure. Both weathered and fresh exposures have a salt-and-pepper appearance caused by black grains of chert, biotite, pyrite altering to lepidocrocite, and carbonized plant fragments. These grains make up 2% to 15% of the rock volume. The dark grains are generally uniformly distributed throughout the rock but some thin sections show slight concentrations of these grains along lamination surfaces.

Sedimentary structures are well preserved in sandstone, but weathering may obscure them, expecially in the thick, lenticular, ledge-forming bodies such as unit 1 of measured section 2. Large scale cross-stratification is the most common and most easily seen structure. It can appear either planar, wedge shaped, or lenticular where exposed parallel to the paleocurrent direction (fig. 5), but is trough shaped (fig. 6) where exposed in section transverse to the paleocurrent direction. The base of each stratification set is usually erosional. Other sedimentary structures found in the sandstone units are horizontal stratification (fig. 7), unidirectional current ripple marks, climbing ripple laminae-in-drift, convolute bedding (fig. 8), and rip-up mud clasts. Root impressions and U-shaped ichnofossils are common in the sandstone (figs. 9 and 10). Molds of bivalve shells are rare.

Some of the lenticular sandstones, unit 3 of section 1 for example, contain nodules of sandstone cemented with iron oxides. The nodules are spherical and up to 2 cm in diameter. These nodules occur mainly along surfaces separating the trough-shaped strata sets, but some may be scattered throughout the rocks. Coarse fragments of plant material that have been replaced by iron oxides also occur along surfaces separating set surfaces in unit 1 of measured section 2. A large, roughly cylindrical iron oxide concretion, 20 cm in diameter and 40 cm high, was found in rubble from this unit.

Clay and silt matrix forms 5% to 10% and calcite, mostly as cement, forms 15% to 20% of the sandstone. Composition of grains that form the remainder of the rock is by percentage volume: quartz, 55% to 65%, potassium feldspar, 10% to 20%, plagioclase feldspar, 1% to 5%, black opaque minerals, 2% to 15%, chert, 1% to 10%, and micas, biotite, chlorite, and muscovite in order of decreasing importance, 1% to 2%. Quartz, potassium feldspar, chert, and opaque mineral grains are equant and angular to subangular. Plagioclase grains are angular and equant to acicular, and micas are angular and platy. An

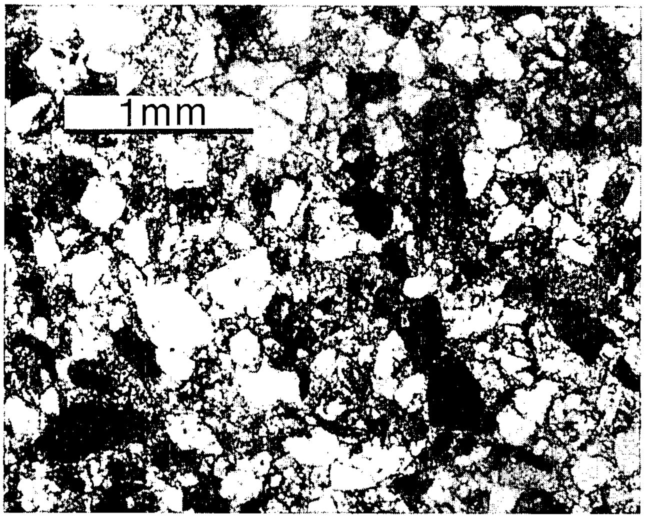

FIGURE 4.—*Thin section of unit 5, measured section 7. Fine-grained sandstone showing dark grains.*

iron oxide stain is common on the grains and iron oxide also acts as a cement, to a limited degree, where it is thicker than a staining film. There is also minor cementation by silica. These sandstones are feldspathic wackes as defined by Williams and others (1982, p. 326–28), but border on being feldspathic arenites because of the low clay and silt content.

Grain size distribution in the lenticular Colton sandstones, as weight percentage determined from sieve analysis, is 0% very coarse or larger, 0% to 6% coarse, 9% to 21% medium, 44% to 54% fine, 6% to 20% very fine, and 8% to 10% silt and clay. These sandstones are 18% to 23%, by weight, soluble carbonate. Exposed sandstones are porous, and sand grains are easily rubbed from the soft, weathered surface. Sandstone exposed at the quarry in unit 3, measured section 7 (fig. 3) has weathered to a typical pale red color, but is hard, well cemented, and light gray just beneath the surface.

Greenish gray-weathering sandstone occurs as large irregularly shaped patches on the pale red weathered surface of one composite set of strata in unit 27 of measured section 5. The composite set above is uniformly pale red, while that below is uniformly greenish gray. Similar intimate relationships of red and greenish gray colors are seen at several other outcrops of thick, composite sandstone ledges. Fluids migrating through these sandstones chemically reduced the red ferric iron in the sandstones to ferrous or lower valences. The nature of this fluid and timing of its migration have not been investigated but this flow is taken as an indication that the sandstones are porous and permeable throughout.

The sandstone from the thick ledges has been quarried at several locations, and the so-called "Kyune" sandstone was used to construct the City and County Building on

FIGURE 5.—*Planar cross-stratification. Exposure in unit 20, measured section 10. Pen shows scale.*

Washington Square in Salt Lake City (Knight 1970). The combination of good permeability and calcareous cement in this stone has led to deterioration of many parts of this building's exterior that are openly exposed to the elements.

Many sandstone outcrops, especially of horizontally stratified bodies, weather too rapidly for the pale red, oxidized exterior to form. These outcrops often have the light gray color more typical of freshly exposed rock.

Sandstone exposed in the lower part of the Green River Formation in Emma Park is similar to that in the Colton Formation except:

1. It is fine or very fine grained. It is well sorted but the mean grain size in many of the units is smaller than in units of the Colton Formation (fig. 11).
2. Iron oxide stain and cement is more abundant and noticeable. The stratification of many sandstone bodies is obscured by bands of iron oxide stain that parallel joints and other zones of permeability (fig. 11).
3. The sandstone weathers yellowish gray to moderate brown, if the oranges from iron oxides are not dominant.
4. Black grains are not as abundant as in the Colton sandstone.

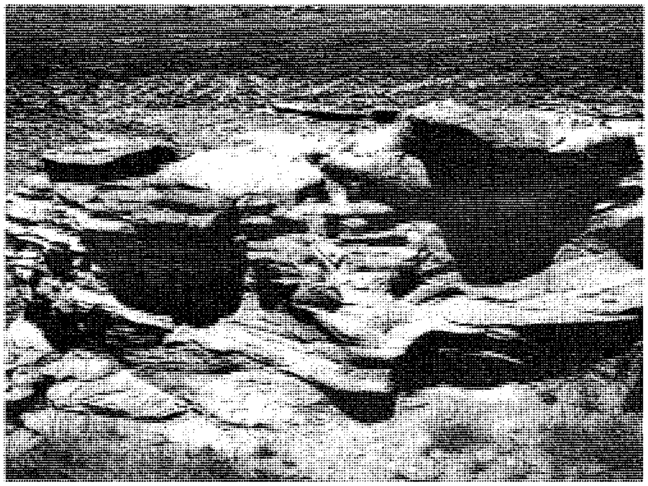

FIGURE 6.—*Trough cross-stratification sets, viewed in downcurrent direction. Coset boundary at left, bottom of ledge. Light-colored slope in background shows where the sandstone dips beneath red mudstone slope. Camera case at center gives scale.*

5. Tabular bodies are more common, although some lenticular, ledge-forming bodies do occur, such as unit 45, measured section 6.

CHANNEL-LAG PEBBLY SANDSTONE

Lenticular channel lag deposits are commonly developed at the base of composite sandstone lenses (fig. 12). Good exposures are seen at units 9 and 35 of measured section 8, unit 20 of measured section 10, and in the large lens exposed in the roadcut just north of the bridge at Kyune. Approximately 20% of a typical channel-lag deposit consists of discoid, well-rounded siltstone and mudstone pebbles with regular, distinct margins, and smaller fragments of the same siltstone and mudstone with irregular margins caused by embedded sand grains. The matrix is sand, silt, and clay similar to the well-sorted sandstones. The cement is calcite, but silica has cemented some of the sand grains into coarse clusters. Coarse and very coarse quartz and chert grains are rare.

The pebbles are aligned parallel to the paleocurrent but there is no true stratification within most of the lag deposits. The bottom contact of lag deposits is erosional and abrupt. Small lenses of poorly sorted medium- to fine-grained sandstone occur within the lag deposits and also sometimes at their base (fig. 12). Upper contacts with overlying sandstone may be either abrupt or gradational. Fragments of fish bones were found in a dissaggregated sample from unit 9 of section 8.

Mudstone and siltstone pebbles similar to those in channel-lag units frequently occur in a mudstone matrix between the large lenticular podlike cosets of point-bar deposits. This is well exposed in the quarry in unit 3 of measured section 7 (fig. 3).

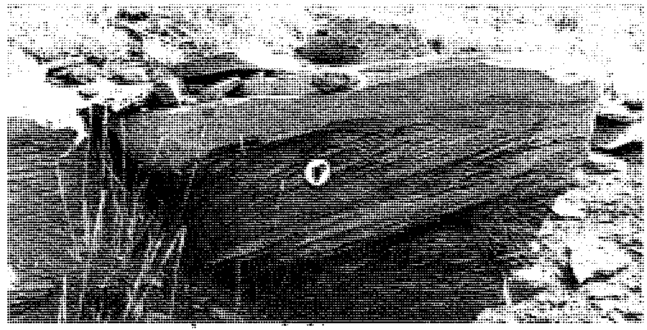

FIGURE 7.—*Horizontal laminations in sandstone. Exposure is at the top of unit 20, measured section 10. These laminations are exposed as climbing ripple lamina-in-drift about 10 m to the west (left). Note erosional contact with overlying, massive appearing trough-shaped sandstone. Compare to plate 4C, Harms and others (1963). Pen gives scale.*

MUDSTONE

The term mudstone is used here in the sense of Ingram (1953) as a fine-grained, nonfissile sedimentary rock consisting of at least 50% silt and clay with no connotation concerning the relative percentages of silt and clay. The mudstone is calcareous. One sample disaggregated in dilute HCl was 34% calcium carbonate by weight. Massive rock that is principally silt is siltstone and is discussed in a later section.

Mudstone is the most abundant rock type in the Colton Formation in Emma Park and typically forms slopes that are pale red, although colors may vary to moderate red, grayish red, and grayish red purple. Color variation is largely due to the relative position of observer, sun, and slope. Some mudstones that occur principally in the middle and top of the Colton Formation, such as units 47, 49, 51, and 53 of measured section 5, weather very light gray to light greenish gray. Flagstaff and Green River mudstones are typically hues of gray.

Mudstone that forms red weathered slopes is dominantly grayish red when wet and freshly exposed, but grayish purple, very dusky red purple, dark greenish gray, and many intermediate colors are also seen. Iron oxide stains in various shades of yellow mark cracks and lamination surfaces. Mudstone that weathers to gray slopes is dusky yellow green to grayish green in fresh wet exposures and is more uniform in color than is the red mudstone. Contacts between red and gray mudstone are gradational, with the poorly stratified pattern continuing from one type into the other.

Shallow digging on steep slopes can often uncover mudstone in place. Erosion in gullies, such as at the bottom of measured section 12 near Kyune, can produce

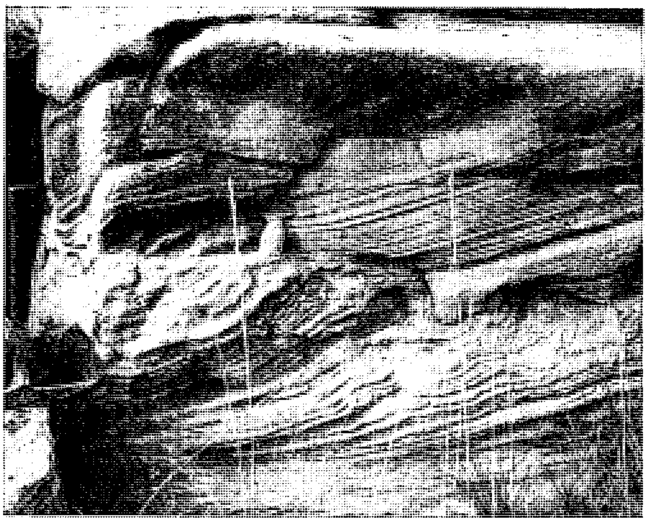

FIGURE 8.—*Disturbed bedding. Cross-bedding appears planer in longitudinal sections, trough shaped in transverse exposures. Distortion of lower strata and deposition of upper strata may have been contemporaneous.*

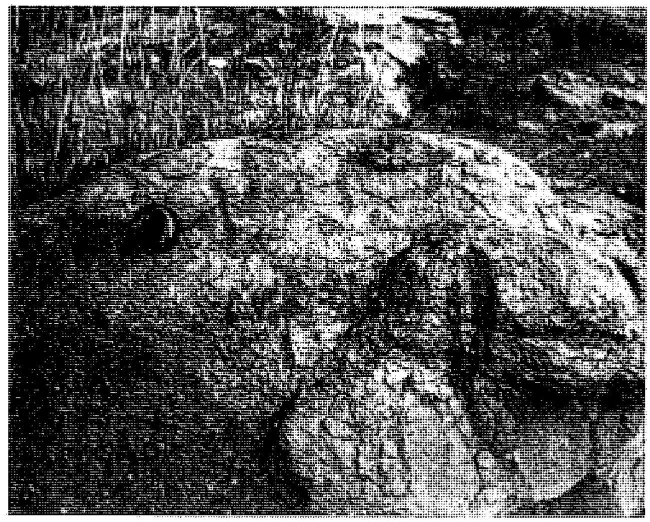

FIGURE 9.—*Root marks exposed vertically in Colton Sandstone. Stratification of sandstone has been partially destroyed. Lens cap gives scale.*

good exposures. The mudstone in these exposures may appear nonstratified and massive or may split into chips or flakes along irregular surfaces parallel to bedding. Flaky shale is the name Ingram (1953) gave to irregularly splitting fine-grained rock, and he considered it gradational with both massive mudstone and fissile, flaggy splitting shale, but not necessarily gradational between them. Mudstone exposed between trough cross-bedded sandstone cosets in unit 20, measured section 10 (fig. 13) is ripple cross-laminated and has flaky splitting. Unit 19 of measured section 10 exposes lenticular beds of nonstratified mudstone (fig. 14).

Contacts of mudstone with the tops and bottom of tabular sandstone bodies are usually abrupt. Contacts with the tops of lenticular sandstone bodies are not exposed in the study area, but contacts at the bases of these sandstones are abrupt and erosional (fig. 12).

No fossils were found in the mudstone in the study area, but one steinkern of a land snail was found lying on a partially exposed mudstone surface. The poorly stratified nature of the Colton mudstone in Emma Park is evidence that plants and animals were disturbing the sediments after deposition, in conditions similar to those described by Hyne and others (1979).

SILTSTONE

Siltstone in the Colton Formation is composed of angular silt-size grains in a clay matrix with additional calcite cement. The siltstone usually occurs in thin tabular beds with no evident sedimentary structures. Surfaces of tabular beds cut and polished normal to the bedding reveal lenticular sets of cross-laminations, but they are still only faintly expressed.

The siltstone is pale red to pale reddish brown on weathered exposures and light brownish gray on fresh ones. The siltstone may contain fine and very fine sand-size grains in a range of textures transitional between a well-sorted sandstone and a siltstone of uniform grain size. The salt-and-pepper appearance typical of the sandstone is usually absent and a thin section of siltstone did not show opaque grains.

SILTSHALE

Silt dominated rock also occurs in clearly cross-laminated, fissile deposits that are often transitional between tabular sandstone bodies and mudstone (fig. 15). These are classified as siltshale (Ingram 1953) due to their fissile nature, but except for their fissility these rocks are similar in appearance to siltstone.

U-shaped ichnofossils occur in both siltstone and siltshale. These burrows are up to 1 cm in diameter and penetrate at least 45 cm. In transitional units such as the top of unit 1 of section 7 (fig. 15), the trace fossils appear to continue down into the sandstone.

SHALE

Principle shale outcrops in Emma Park are in the Green River Formation. They can be generally divided into two types: light bluish gray-weathering shales with papery splitting, and yellowish gray-weathering shales with papery to shaly splitting. Neither type contains significant silt so they are clayshales in Ingram's (1953) system, but the generally understood term "shale" is used to refer to these rocks throughout this study.

The light bluish gray-weathering shales are olive gray to dark gray on a fresh exposure and have a petroliferous

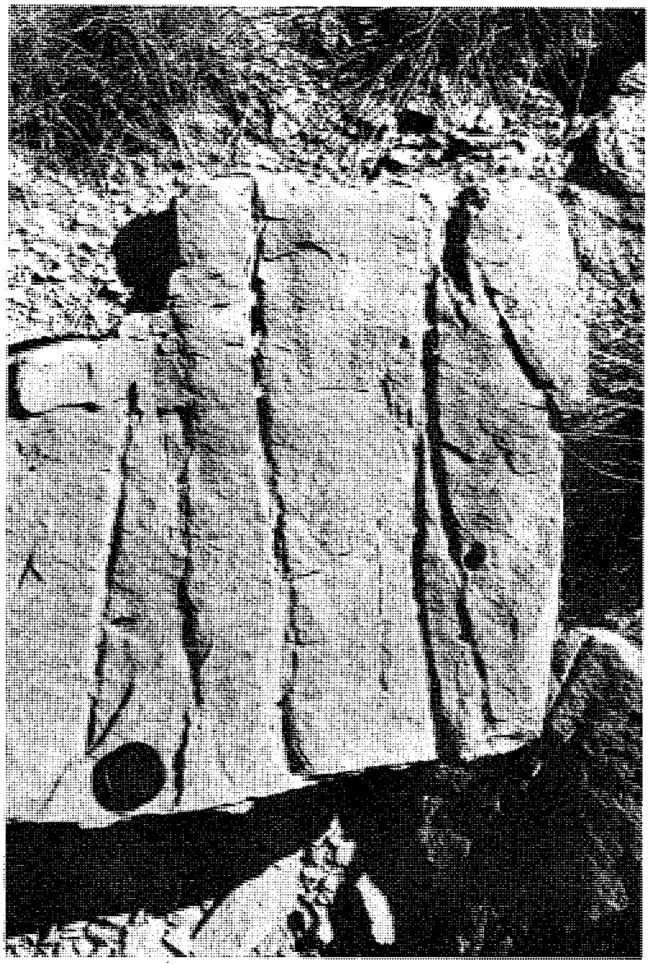

FIGURE 10.—*Vertical exposure of* Arencolites *type burrows in Colton sandstone. Lens cap gives scale.*

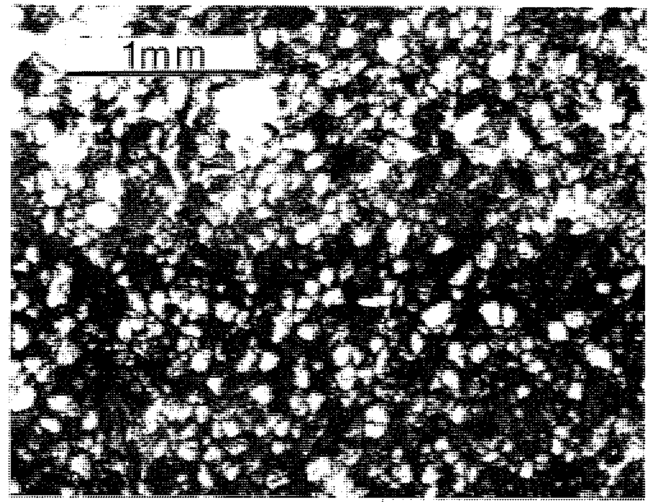

FIGURE 11.—*Very fine-grained sandstone from the Green River Formation. Dark material at bottom is iron oxide stain.*

odor when broken. Outcrops are poor and usually consist of a few exposure of in-place rock poking through patches of papery rubble on the slope. The shale is calcareous. Cashion (1957) identified blue-gray weathering as typical of organic rich oil shales.

The yellowish gray-weathering shales are light gray to moderate brown on a fresh exposure and are very calcareous. Exposures are poor but the shale is seen where it is protected by ledge-forming limestone, such as in units 10 and 11 of measured section 2. Contacts between the two shale types are not exposed, but the pattern of exposures and rubble indicate that the two shales were deposited in adjacent environments and probably grade into each other.

Neither body fossils nor ichnofossils were seen in the shales except at the west edge of the area where small fragments of thin shells, probably ostracod valves, occur in silty, thinly laminated shale at the top of measured section 12.

Outcrops of fissile, laminated shale, as opposed to more massive mudstone, are rare within the Colton Formation, but such shale does occur irregularly in exposures in the uppermost part of the formation where limestone units also appear. These shales are similar to those of the overlying Green River Formation.

LIMESTONE

Limestone is common in the Green River Formation, above, and the Flagstaff Formation, below the Colton Formation. Limestone within the Colton Formation appears to be a result of transitional lacustrine to deltaic environments. The system of Dunham (1962) was used to classify the limestones. The modifier "lime" not only indicates lack of dolomite in these rocks, but is also useful to distinguish carbonate mudstone from the clastic mudstone described earlier.

Carbonates of the Green River–Colton Transition Zone

Lime Mudstone-Wackestone. These rocks usually weather yellowish gray but may be pale to moderate red if enclosed within red mudstone units. Fresh exposures are medium gray to dark yellowish brown, and hydrogen sulfide is often released when the rocks are broken. These limestones may contain a fair amount of silt and sand. Fossils may be absent but small fragments of mollusk shells, either unaltered or recrystallized to calcite (fig. 16), commonly form 1% to 2% and occasionally as much as 10% of these rocks. Whole bivalve shells, both articulated and disarticulated, are found oriented parallel to stratification in unit 9, measured section 1 (fig. 17). This same unit contains about 5% large fragments of gastropod shells and also about 50% sand grains, bordering on being a sandstone. Lime mudstone-wackestone occurs as single

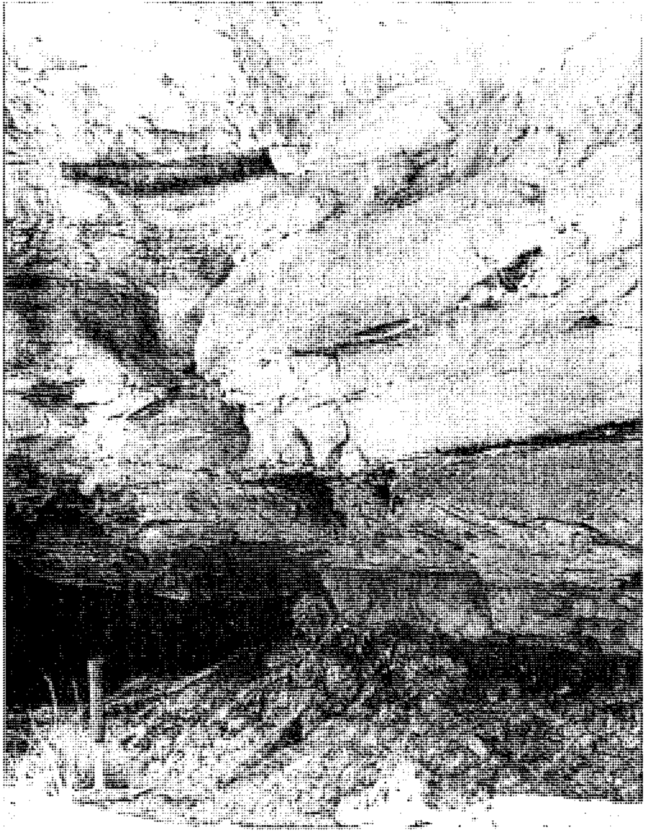

FIGURE 12.—*Channel-lag sandstone. Basal contact with mudstone is abrupt, erosional, and trough shaped. Channel lag contains rounded pebbles of mudstone plus medium- to coarse-grained sand. Overlying sandstone is cross-laminated at very low angles, appears horizontal over much of the exposure.*

thin beds that contain no sedimentary structures. Top and bottom contacts are generally abrupt.

Beds are hard and resistant. They form thin ledges but are often covered on steep slopes. There probably are more of these thin limestone beds than were actually seen. Exposed examples in the Colton Formation are units 3 and 5 of measured section 2. Unit 9 of measured section 1 lies just above the Colton–Green River contact.

Laminated Lime Mudstone-Wackestone. Laminated lime mudstone-wackestone is similar to lime mudstone-wackestone except that it occurs as sets of parallel laminations that have gradational contacts with overlying shale or mudstone. The bottom contact can be either abrupt or gradational into shale. Some exposures are cross-laminated but most have horizontal laminations. Examples are units 18 and 20 of measured section 3 in the Green River Formation.

Bivalve-Gastropod Lime Packstone. Whole to crushed shells of *Unio* bivalves and *Goniobasis* snails are closely packed, and the interstices are filled with lime mudstone in these packstones (fig. 18). *Goniobasis* shells form up to 90% of the total rock volume. Swain (1956) referred to rocks of this type in the Uinta Basin as "*Goniobasis* coquinites"; coquinites being compact, well-indurated and firmly cemented equivalents of a coquina. *Goniobasis* shells are abraded, but fine detail is preserved on many. The shells lie parallel to stratification with random orientation, and the rock has discontinuous wavy, nonparallel thin laminations. The packstones occur in single thin sets of these wavy laminations and form ledgy slopes. The rock has a slabby weathering habit. Top and bottom contacts are gradational. This packstone weathers very light gray and the fossils stand out in relief (fig. 18). A fresh exposure is medium gray mottled with different shades of brown and gray and with unaltered shell nacre. Units 22 and 24 of measured section 3 are examples.

In Emma Park this packstone occurs consistently a short distance above the ostracod lime packstone that is described below. Whether or not it is one laterally continuous unit throughout the area studied is not evident from the exposures.

Ostracod Lime Packstone-Wackestone. Ostracod shells are closely packed but are not completely crushed or deformed in these distinctive limestones (fig. 19). The shells, including the internal cavity, form up to 80% or 90% of the rock volume. The matrix is lime mudstone and the shells are frequently unfilled so that the rock has good moldic porosity. In some samples the shells are unoriented, but in others the valves are roughly oriented parallel to bedding, which produces very thin, wavy, discontinuous laminations (fig. 20). Ostracod distribution may be fairly uniform, but in thicker beds the shells are less abundant or absent in the lower part. Shells are partially replaced by iron oxide in some samples.

These rocks are hard, resistant, and form prominent angular ledges (fig. 3). These limestones occur in thin beds, either as sets of several uniform beds separated by abrupt contacts, as sets with alternating limestone and shale layers separated by abrupt contacts, or with shale grading up into limestone. Good examples are units 11, 13, and 15 of measured section 2.

The ostracod lime packstone-wackestone weathers yellowish gray to grayish orange and is light olive gray on a fresh exposure. A petroliferous odor is frequently released on fresh breaks. Fresh surfaces often display irregular bands or lenses of lime mud where shells are absent. Valve cavities are filled with dark material, probably kerogen (fig. 20) in unit 60, measured section 5.

Carbonates of the Flagstaff-Colton Transition Zone

Lime Mudstone-Wackestone. These medium gray rocks dominate the upper Flagstaff Limestone in Emma Park. They are similar to the lime mudstone-wackestone of the Green River–Colton transition zone except that

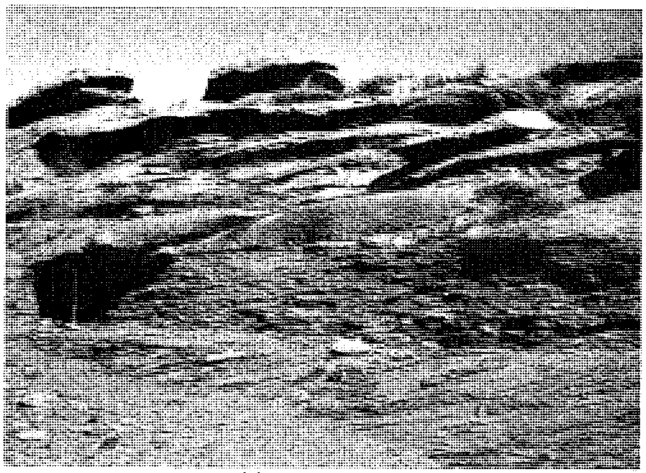

FIGURE 13.—*Ripple cross-laminated mudstone set separates cosets of trough cross-bedded sandstone in unit 20 of measured section 10. Hammer for scale.*

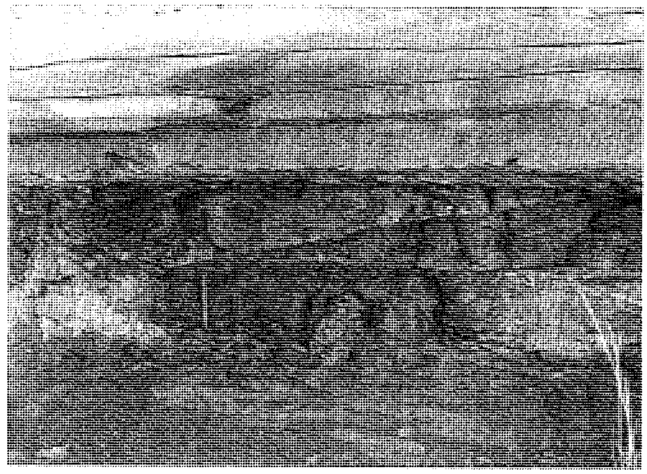

FIGURE 14.—*Lenticular, thick beds of mudstone, unit 19, measured section 10. Thin basal lag deposit and very low-angle cross-stratified sandstone of overlying channel deposit. Pen for scale, approximately 15 cm.*

they occur in sets of thin beds, often with very thin mudstone deposits between sets. These limestones lack visible sedimentary structures, but unit 3 of measured section 10 has platy splitting. Top and bottom contacts are abrupt. The rock is hard and resistant. Streams in the valley bottom flow across the bedding surfaces and cut laterally downdip rather than cut down through the limestone. Such exposed bedding surfaces are irregular, cusped, and very rough. There are well-developed joint sets on these exposed bedding surfaces. These rocks are well exposed in gullies near the road on measured section 9.

Fossiliferous Lime Packstone. Two distinct types of fossiliferous lime packstone were found in the Colton–Flagstaff transition zone.

The first occurs in only one exposure, unit 10 or measured section 10 on the east edge of the study area. There the packstone contains small, whole *Hydrobia* gastropod shells, fragments of bivalve shells, and broken algal structures. Fossils lie parallel to stratification. Fossil distribution produces a graded effect within the rock. The top and bottom of the bed are 20% sparite-filled, whole *Hydrobia* shells and 30% broken algal structures in a lime mudstone matrix. The middle of the bed is about 5% lime mudstone but consists mainly of algal structures and brown, amorphous organic material that have been compressed around 5% to 10% crushed *Hydrobia* shells and deformed mollusk and ostracod fragments (fig. 21). A freshly cut surface of this rock shows that the middle of the bed is grayish brown and the top and bottom are uniform dark gray.

Algal-ball or oncolite lime packstone, the second type, is well exposed in unit 3 of section 5. This packstone is present in a limestone unit that forms a series of cuestas along the valley bottom across most of the area (fig. 3). Matts Summit is located where the county road crosses one of these cuestas (fig. 2). This rock is characterized by abundant algal-balls or oncolites formed around *Viviparus* shells (fig. 22). Whole oncolites form up to 50% of the rock, and fragments pack the spaces between the oncolites. Matrix is lime mudstone. In unit 20, measured section 9, rip-up clasts are more abundant than oncolites (fig. 22D). The limestone unit is thin bedded. Within a single bed the packstone may grade into lime wackestone containing fragments of shell and algal material and into lime mudstone. Oncolites may occur at the top or bottom of beds. The two oncolite beds exposed in unit 2 of measured section 12, at the west edge of the area, are between beds of lime mudstone. The oncolite lime packstone exposed in measured sections 5 and 9 in the central part of the area is at the top of the limestone sequence. Oncolites are absent in equivalent beds at the east edge of the area near Utah 33.

Oncolites in exposures near Matts Summit Pass are up to 6 cm in diameter (fig. 22B). The thick algal crusts of the larger ones have both radial and concentric cracks that are filled with lime mudstone and small clasts. The viviparid snail shells are up to 2 cm across, at the body whorl (fig. 22C), and are filled with lime mudstone, small clasts of algae, and smaller snail shells that are not covered with algal crusts (fig. 23). The snail shells are recrystallized to calcite. Larger oncolites weather out of the matrix and litter the rim of the cuesta near the highway at Matts Summit. Where the oncolites do not weather out as balls they weather to dark gray circles and spirals in the light olive gray matrix, (fig. 22A, D).

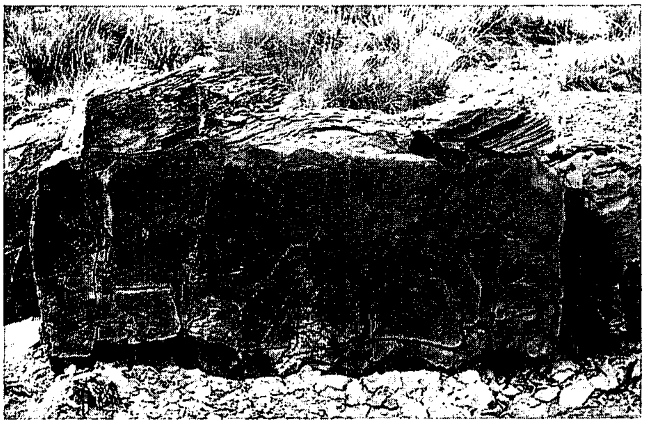

FIGURE 15.—*Massive, tabular sandstone grading upward to cross-laminated siltshale. Horizontal and vertical burrows are visible.*

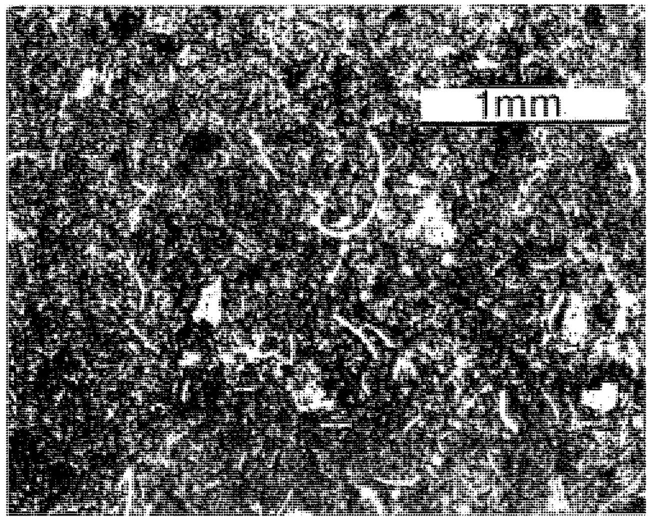

FIGURE 16.—*Lime wackestone with mollusk shell fragments.*

Intraformational Conglomerate Lime Packstone. This type of packstone consists of 80% to 90% rip-up clasts of lime mudstone in a lime mudstone matrix (fig. 24). The clasts are similar to those found with the algal-ball lime packstone (fig. 22D). The lateral and vertical relationships of this rock to the algal-ball lime packstone and the presence of similar rip-up clasts in both units indicate that depositional environments for the two rock types were laterally related, even though the two rocks cannot be traced directly into one another. The rip-up clasts are angular and range from sand-size up to several centimeters across. Both the rip-up clasts and surrounding matrix contain angular silt grains. The silt makes up less than 1% of the total rock but as much as 5% of some of the rip-up clasts. Ostracods and small gastropods with crystalline calcite-filled centers are found within the rip-up clasts, and fragments of ostracod shells are found in the matrix. The rock weathers grayish orange to very light gray and forms a broken, angular, thin ledge. This conglomeratic to brecciated packstone is exposed as one thin bed, unit 8 of measured section 10.

DESCRIPTION OF LITHOLOGIC BODIES

The main frame-building deposits of the Colton Formation are sandstone lenses and sandstone and siltstone sheet deposits. Sheet deposits are commonly laterally equivalent to the sandstone lenses. Terminology as proposed by McKee and Weir (1953) is used in describing the sandstone deposits.

SANDSTONE LENSES

These sandstone bodies display a vertically lenticular shape in outcrops in Emma Park. Sandstone lenses of the Colton Formation in Emma Park are exposed as large, tabular appearing bodies such as unit 3 of measured section 7 (fig. 3), as multistory bodies such as unit 40 of measured section 8 (fig. 3), and as small to large isolated outcrops such as those seen along the West Fork of Willow Creek (fig. 25). The thickest isolated lens measured is unit 1 of measured section 2 that is 16.5 m thick at its western end (fig. 25). The well-exposed multistory lens east of unit 46 of measured section 8 is at least 25 m thick. The tabular appearing body that is unit 40 of measured section 8 and also unit 1 of measured section 4 is approximately 1 km wide and forms the top of a multistory sequence at least 30 m thick (fig. 3). These lenses are flat-topped and typically form high ledges where sedimentary structures may be well exposed. The lenses are asymmetrical and have slightly concave bases. They gradually thin laterally. Lenses are vertically enveloped in mudstone and grade laterally into platy-splitting sandstone and siltstone. Sedimentary structures become less pronounced and mudstone becomes interstratified with the coarser deposits at edges of the lenses. Abrupt lateral terminations of sandstone lenses against slope-forming mudstone can be seen (fig. 25 and unit 16 of measured section 7). Details of these contacts are not exposed but the lenses weather out in a cavernous manner adjacent to these terminations, atypical of most Colton sandstone units.

Colton sandstone lenses are generally composed of a basal channel-lag deposit (fig. 12), overlain by imbricate, asymmetrical, lenticular cosets of fine-grained sandstone. The cosets may be distinct bodies separated by mudstone and siltstone deposits (fig. 13) or may be almost indistinguishable from each other in massive-appearing ledges. The inclined, imbricate overlapping cosets make up the bulk of each sandstone lens.

Basal contacts of sandstone lenses are irregular erosional surfaces, usually scoured into mudstone (figs. 12 and 14). Exposures are limited, but lenticular channel-lag

FIGURE 17.—*Sandy fossiliferous lime wackestone. Articulated bivalves lie parallel to bedding.*

deposits of sandstone containing mudstone pebbles generally form the base of the lens (fig. 12). These lag deposits are laterally irregular and may be missing, either by syndepositional erosion or by nondeposition. Well-sorted sandstone lies directly on the scoured surface where channel-lag deposits are missing (fig. 14). Units 9 and 35 of measured section 8 are well-exposed lag deposits that show these relationships.

Tabular-appearing sets of horizontal strata are exposed in the lowest part of some sandstone lenses (figs. 12 and 14). Stratification within these sets is parallel, either horizontal or cross-stratified at very low angles, and is often indistinct. An example is unit 10 of measured section 8, which changes upward abruptly from a horizontally laminated, well-sorted sandstone to a ripple cross-laminated siltstone.

Sets of medium-scaled trough cross-stratified sandstone (figs. 5, 6, 8, and 13) overlie the basal lag deposits and sets of horizontal strata. These cross-stratified sets are the dominant structure of the lenticular cosets and of the sandstone lenses as a whole. Directions of dip of cross-strata are unimodal and indicate the direction of sediment transport in the local environment (fig. 8). Concave up trough-shaped or festoon-shaped sets are the most common type of cross-stratification (figs. 6 and 8). The basal surface of each set is erosional and truncates strata of underlying sets. Strata within each set are laminated to very thin bedded, parallel, and in transverse section are

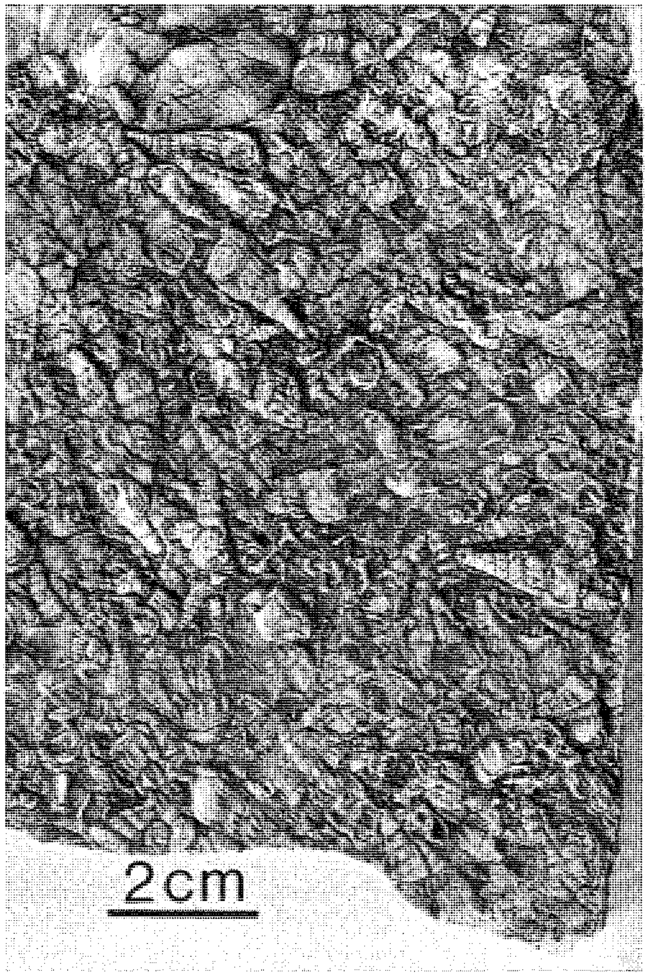

FIGURE 18.—*Bivalve-gastropod lime packstone.* Goniobasis, *crushed but whole and with well-preserved ornamentation lie horizontally with random orientation. Crushed, whole* Unio *valve is seen in upper left corner.*

parallel to the curve of the bottom of the set. Individual sets are often difficult to distinguish. Iron oxide stains may faintly indicate strata and strata set surfaces, but typically the sandstone ledges split into massive blocks and weather to rounded massive forms (fig. 25) through exfoliation and dissolution of calcite cement, often across set boundaries. Weak cement, or mud and silt along set boundaries, frequently allows weathering to expose shapes of sets and cosets (figs. 6 and 8).

Cross-strata that are parallel and dip in one direction are seen in tabular, wedge-shaped, and lenticular sets. Good exposures of this type are seen in unit 20 of measured section 10 (figs. 5 and 8). These cross-strata are commonly only different vertical views of trough-shaped sets along surfaces that parallel the sediment transport direction. Exposures transverse to transport direction show trough-shaped sets. Generally these three dimensional relationships are easily seen in the field (fig. 8).

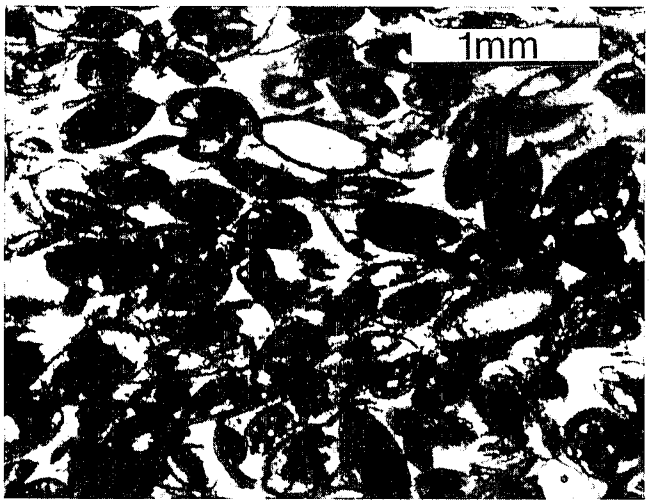

FIGURE 19.—*Ostracod lime packstone. Cement is silica, dark material is ferrous iron.*

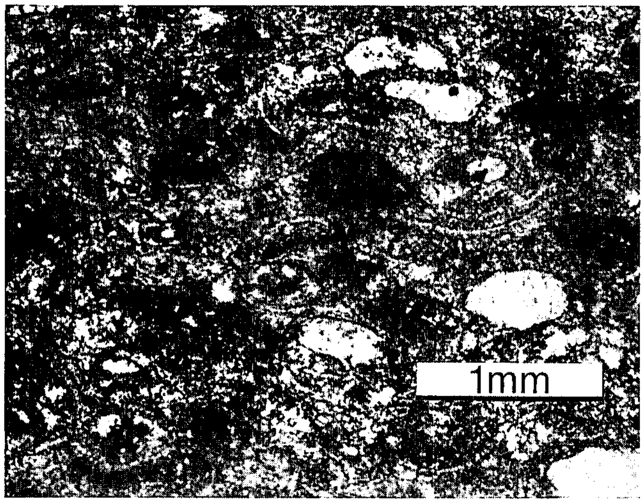

FIGURE 20.—*Ostracod lime packstone with valves roughly paralleling stratification and forming faint wavy laminations. Matrix is lime mudstone. Dark material is probably kerogen.*

Such sedimentary structures continue to the top of the cosets. Rims of sandstone ledges are sometimes marked, where sets have weathered away, by crude trough-shaped depressions separated by rounded ridges, both having current oriented axes.

Root marks and U-shaped burrows are also common at the top of sandstone lenses. Other fossils are very rare anywhere in the lenses.

Red slope-forming mudstone generally overlies sandstone lenses; tops of ledges are partially covered by debris, and details are rarely exposed (fig. 25). Horizontally very thin-bedded sandstone is poorly exposed in unit 4 of measured section 1 above a thick sandstone lens. Thin, tabular sets of climbing ripple laminae-in-drift, which grade laterally into horizontal laminations (fig. 7), are exposed in unit 22 of measured section 10, near the top of a composite sandstone lens.

SHEET DEPOSITS

Sandstone, siltstone, and rocks transitional between the two occur in tabular flat-bottomed and flat-topped units. Sheet deposits are frequently seen as lateral continuations of sandstone lenses, such as units 6, 7, and 8 of measured section 5. Exposures are not extensive but rubble, color variations, and vegetation patterns indicate these sheets extend tens and possibly hundreds of meters laterally. Edges of these sheet deposits, away from the sandstone lenses, were not seen in exposures in Emma Park. Exposures in deeply eroded gullies show that sheet deposits are more abundant than weathered outcrops indicate.

Most sheet deposits of silt and silt-sand composition appear featureless in outcrops, except for occasional U-shaped burrows. Cross-stratification is seen in some exposures (fig. 15) and on cut and polished surfaces. Top and bottom contacts are irregular and may have some poorly preserved ripple marks. Mudstone generally lies above and below these deposits, with abrupt contacts. Thicknesses range from 5 cm to several meters. Thinner units tend to be ledge formers and thicker ones, such as unit 12 of section 1, are slope formers. Unit 34 of section 8 weathers in an atypical rounded, almost spherical, manner that Peterson (1976) attributed to a dominant clay content in deposits to the west.

Sheet sandstone units may be featureless, cross-stratified, or horizontally stratified. Featureless or indistinctly stratified sandstone sheets are similar to featureless siltstone as burrowed, thin, ledge formers enclosed between mudstone. Internally stratified sandstone sheets range from 5 cm to several meters thick and form ledgy slopes. Sandstone in these units ranges from fine grained and well sorted, similar to that in sandstone lenses, to very fine grained and silty. Platy splitting is typical and mudstone is commonly interlayered with the sandstone. Root marks are common. The rock often erodes too rapidly for a red colored exterior rind to form, and light gray is a typical color.

Some very thin-bedded to laminated sheet deposits are truly horizontally stratified, such as those at the bottom of measured section 12. Many other units are cross-stratified at very low angles, often with subtle "trough" shapes, but they do not form lenticular strata sets. Unit 6 of measured section 5 shows this low angle cross-stratification at the east end of the outcrop and grades laterally into a sandstone lens approximately 100 m to the west. Units 7 and 8 are similar to unit 6, and these three display several structures of stratified sheet sandstones: climbing ripple cross-lamination, rip-up clasts, burrows, and root marks.

Stratification has been partially or wholly destroyed through bioturbation in some parts of these exposures, and root marks and burrows are generally less distinct than on sandstone lenses.

Limestones in the Flagstaff Formation and Green River Formation and uppermost Colton Formation also occur as sheet deposits. Ostracod and *Goniobasis* lime packstones provide the best key units for correlation of the measured sections along the Emma Park strike valley because they are much more laterally extensive than the clastic sheet deposits, and are usually well-exposed ledges (fig. 25). Details of limestone units have been discussed in the section on lithology.

FOSSILS

Body fossils are well preserved in limestone units in the study area, but are rare in the sandstone, siltstone, and mudstone of the deltaic-fluvial rocks. This may reflect the relative abundance of hard-bodied organisms in the two

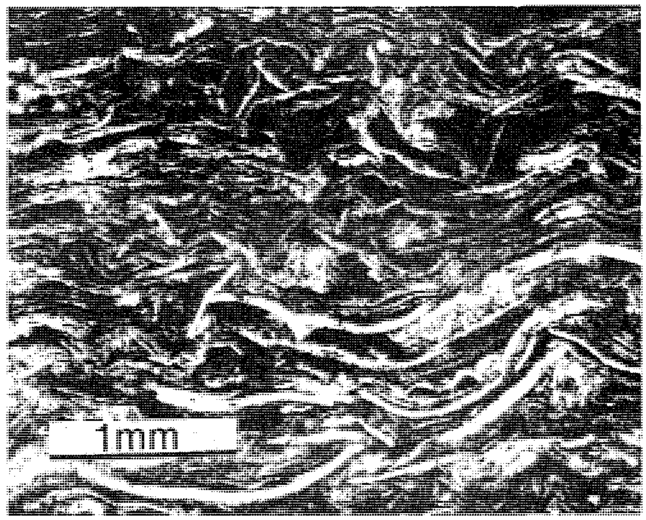

FIGURE 21.—*Fossiliferous lime packstone of the Flagstaff-Colton transition zone. Broken and compacted algal structures. Dark is black to dark brown amorphous organic material.*

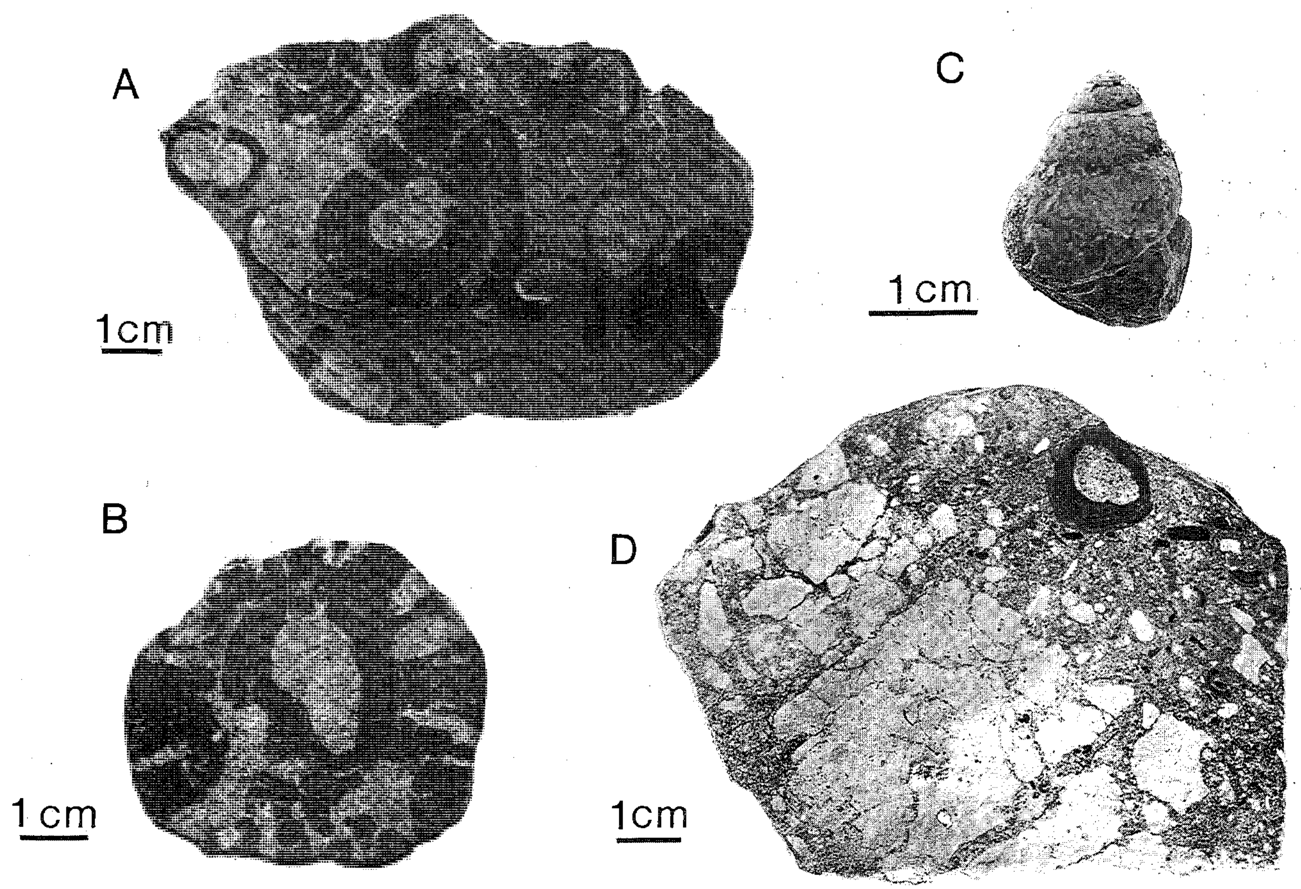

FIGURE 22.—*(A) Polished surface showing various thicknesses of algal deposits around* Viviparus *shells. (B) Section through a large oncolite that had weathered free. Radial and concentric cracks and shell interior filled with algal fragments and lime mud. (C)* Viviparus *from interior of an oncolite. (D) Rip-up clasts of lime mudstone, oncolite, and algal fragments in matrix of lime mudstone.*

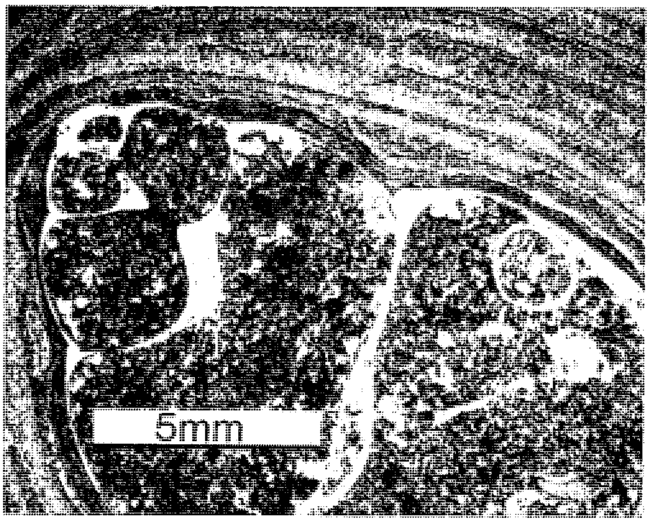

FIGURE 23.—*Detail of* Viviparus *and algal structure of Flagstaff oncolite. Shell cavity entirely filled with algal fragments, gastropod fragments, and lime mud. Note especially small, gastropod shells, possibly* Hydrobia.

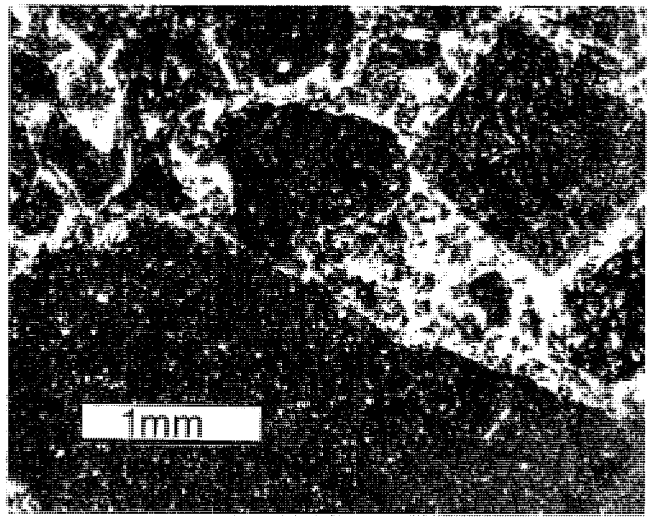

FIGURE 24.—*Intraformational conglomerate lime packstone. Silt grains within the lime mudstone clasts.*

environments at the time of deposition, as well as destruction of fossils in the abrasive high-energy conditions in the channels, coupled with poor exposures of the overbank deposits.

Ichnofossils, which are formed after deposition of the sediment (Seilacher 1964), are abundant in sandstone and siltstone units. The poorly exposed mudstone units reveal no identifiable trace fossils, but their disrupted stratification indicates that plants and animals were actively rooting and burrowing through them after deposition, under conditions similar to those described by Coleman and others (1964) and Fisher and Brown (1972, p. 42).

Fossils found in the Colton and overlying and underlying formations include bivalve and gastropod shells and fragments, ostracod valves, plant fragments and algal structures, and ichnofossils of both plants and animals. Unbroken and unabraded fossils are present in some units, but fragments and crushed specimens are more common. Recrystallization to sparry calcite is the usual mode of preservation of calcareous shells, but many are also unaltered. Hematite has partially replaced some of the calcareous fossils. One sample from unit 13 of section 2 has ostracods preserved as calcareous valves in a silica cement (fig. 19). Plant fragments are preserved by carbonization and by replacement by iron oxide. Amorphous brown material, probably kerogen, is found in several beds, in unit 31 of section 3, for example.

GASTROPODS

The only body fossil found in the red beds of the Colton Formation is an internal mold of a gastropod. The mold in red siltstone was found as float from unit 21 in section 7. No detail is preserved, but the size, shape, and whorl pattern are documented. The fossil is similar to the air-breathing gastropod "*Helix*" identified from the Flagstaff Formation by La Rocque (1956, 1960).

Limestone at the top of the Flagstaff Formation across most of the study area (e.g., unit 4 of section 5) contains *Viviparus* shells as cores of algal-ball oncolites (fig. 22). These shells are well preserved and are rarely broken. They are uniformly large, up to 2 cm in diameter at the body whorl, and represent mature organisms. Thin sections show details of the skeletal and algal structures and also smaller gastropods that are not covered with algae (fig. 23). *Viviparus* is a common fossil in the Flagstaff Formation. These snails usually lived partially buried in a soft muddy bottom in shallow, turbid, wave-agitated water and were gill breathers according to La Rocque (1956, 1960).

Small gastropods identified as *Hydrobia* are associated with algae in unit 10 of section 10 (fig. 21). Their shells are up to 2 mm in diameter at the body whorl, are dextrally coiled and conical. Their whorls are slightly convex to almost flat sided on lower whorls. *Hydrobia* of similar size and shape are associated with algae in Flagstaff beds elsewhere according to La Rocque (1956), who reported it as a gill breather that preferred life either on a hard bottom where there was a thin cover of microscopic plants or on stems and leaves of aquatic plants (La Rocque 1956, p. 143–144).

Goniobasis tenera Hall are abundant in thin coquinite beds at the bottom of the Green River Formation, (e.g., unit 17 of section 1). The shells are crushed but otherwise well preserved. Shell ornamentation is well preserved on weathered surfaces (fig. 18). These beds also contain crushed *Unio* valves but *Goniobasis* forms more than 90%

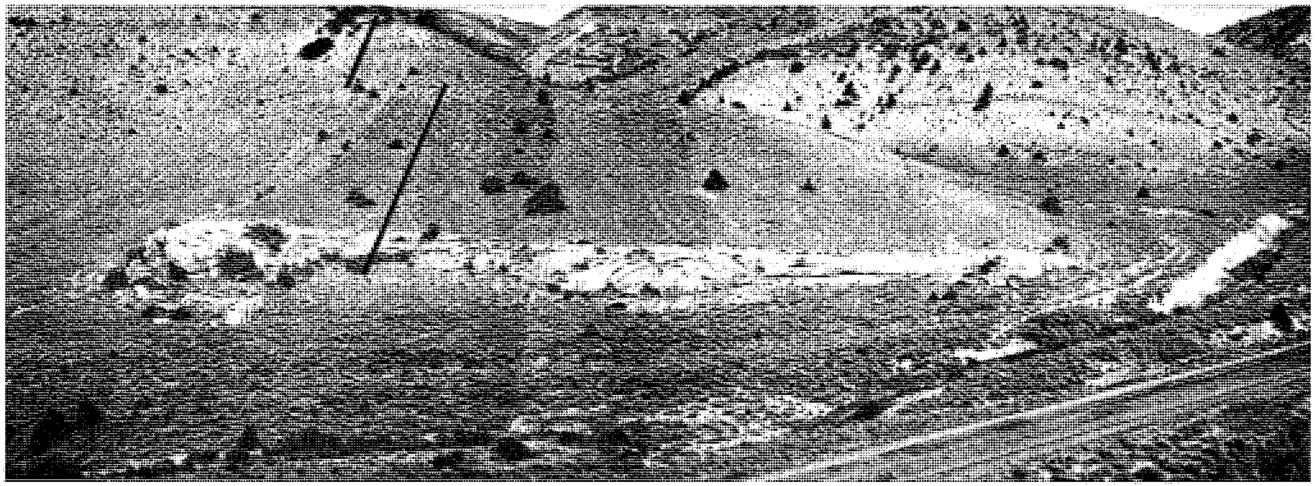

FIGURE 25.—*Lenticular sandstone deposit at confluence of Willow Creek and West Fork of Willow Creek, 16.5 m exposed at southwest (left) end. Color change at Colton–Green River contact is clearly seen in background, below thin ledge of ostracod lime packstone.*

of the bioclasts. *Goniobasis* has spiral ornamentation over the entire whorl and strong axial plications on all whorls, but no nodes. They correspond to type B of La Rocque (1960, p. 28–31) that occur commonly in upper Flagstaff deposits.

Judging from living *Goniobasis* species, these snails were gill breathers and preferred a soft muddy bottom in shallow, wave-agitated turbid water. They were not easily transported and probably laid eggs on solid objects, such as on clam and gastropod shells and rocks.

PELECYPODS

Bivalve fragments are present in almost every limestone examined. Whole, closed shells are present in unit 9 of section 1, at the base of the Green River (fig. 17), and in unit 4 of section 9 in Flagstaff Limestone. These are *Unio (Elliptio)* sp. Crushed valves are found elsewhere with *Goniobasis* and are also probably *Elliptio* (fig. 18). Molds of bivalve shells are found rarely in sandstone lenses in the Colton Formation and Green River Formation, as for example in unit 45 of section 5, but they are indistinct and not even generically identifiable.

These pelecypods are poor environmental indicators because they apparently lived in a broad range of freshwater habitats. Modern *Elliptio* are epifaunal dwellers, and their larvae must be carried parasitically in gills of fish during the life cycle.

OSTRACODS

Ostracods occur in abundance in the ledge-forming limestones that lie above the Colton–Green River transition (fig. 25). These fossils are approximately 0.5 mm long, reniform, with thin smooth valves (fig. 19). Valves as long as 1 mm are occasionally seen among the smaller ones. Most valves have been partially crushed but otherwise are intact, commonly with the two valves closed, and unabraded. Many of the rocks are composed of shells that lie nearly horizontally while others appear to be oriented irregularly. Ostracods found in Emma Park are in a lime mud matrix. The unabraded, partially crushed, but otherwise intact valves are often closely packed (fig. 19). Ostracods collected in the present study were not generically identified.

Swain (1956) collected ostracod fossils from a section along Willow Creek, which corresponds in part to the stratigraphic interval covered in section 2 of this study, but his generalized stratigraphic section cannot be correlated with that measured section 2 of plate 1. Swain (1956) identified the ostracods he found as members of the freshwater family Cypridae.

Ostracod species are selective of their habitat, and congeneric species may live in very different environments. Most freshwater ostracods live in shallow, quiet, often stagnant water. They live in or on muddy bottoms, on plants, and a few species are free swimming. Ostracods are omnivorous scavengers, living on protozoans, algae, and detrital waste material (Benson 1961).

ALGAE AND PLANTS

Algae around *Viviparus* shells formed oncolites of the Colton-Flagstaff transition beds (figs. 22 and 23). Fossil algal filaments are not preserved in these "algal-balls" but algae produced an organosedimentary structure from their interaction with the sedimentary environments. Oncolites in exposures near Matts Summit Pass are up to 6 cm in diameter (fig. 22). The larger ones have both radial and concentric cracks in the thick algal coating that are filled with lime mudstone and small clasts. The viviparid snail shells are up to 2 cm across, at the body whorl, and are filled with lime mudstone, small clasts of algae, and smaller snail shells that are not covered with algal crusts (fig. 22). The snail shells are recrystallized to calcite.

Oncolites form in shallow, continuously agitated, water when suitable organisms attach themselves to a freely moving host. Sediment is trapped and bound to all sides as the oncolite grows and is rolled around on the substrate (Logan and others 1964). Filamentous green and blue-green algae were probably the active agents in forming the Emma Park oncolites, as at other Flagstaff oncolite locations (Eardly 1932). Water in Lake Flagstaff was rich in calcium (La Rocque, 1960) and photosynthesis by these algae would have precipitated $CaCO_3$ to form the layers. The abundant lime mud in the matrix of the oncolite-bearing rocks was probably produced, at least in part, by this same process.

The common broken large oncolites were probably cracked during storms and other times when movement was more violent than normal. Collision could have caused the thick algal layer to crack and to break apart along weakly cemented surfaces. Associated rip-up clasts were probably introduced from nearby dried mud flats during these storms.

Algal structures are also found in unit 10 of section 10. These algae were probably growing in quiet or stagnant water and accumulated as a loose mat containing gastropod, ostracod, and bivalve shells and fragments, along with macerated plant material (fig. 21).

Root marks are common in sandstone lenses, especially near the top of the lenses, and in stratified sheet deposits (fig. 9). Actual plant materials are not preserved, but rather zones of branching discoloration now show where the roots once grew. The traces are very irregular in diameter but some up to 30 cm long are exposed in units 6 and 7, section 5, where downward branching is evident. Root marks were not seen in massive sheet deposits nor in poorly to nonstratified mudstone, but it is the lack of internal structure in these sediments that indicates they probably were subject to constant disruption by burrowing animals and plant roots.

No identifiable fossils of large plants were found in Emma Park. Limb or stem fragments were found in some sandstone lenses along surfaces between strata sets and cosets, as for example in unit 1 of section 2.

TRACE FOSSILS

Arenicolites-like cylindrical burrows, up to 1 cm in diameter, are common in clastic sheet deposits and in upper parts of sandstone lenses. They typically are seen on exposed horizontal surfaces as simple cylindrical holes but sometimes have a rounded or funnel-shaped depression at the surface. Vertically exposed burrows (fig. 10) penetrate at least 45 cm in unit 1 of section 7, but others probably go deeper elsewhere. No exposure of a complete U-shape was seen, but rocks exposing vertical burrows also expose horizontal burrows with similar size and appearance (fig. 15). Cut and polished surfaces show burrows are filled by siltstone, have no visible wall structure, and surrounding sediment is not disturbed.

These burrows are probably Dominichnia, as classified by Seilacher (1964): permanent shelters for vagile animals that fed outside the burrows or that filtered food from water they drew through the burrow from outside.

GENERAL STRATIGRAPHY

Large flatirons that form the south side of Emma Park are eroded from the Flagstaff Limestone of Paleocene age. Models of deposition proposed by La Rocque (1960) and Stanley and Collinson (1979) indicate that the Flagstaff was deposited in a freshwater lake, the final stage of infilling of a foreland basin from the waning Sevier orogeny to the west. Laramide folding and faulting were raising the terrain to the east, blocking drainage and producing the sediments that were transported to the easterly shores of Lake Flagstaff. Feldspar-rich sands from the Monument uplift of southeastern Utah and the Uncompaghre upwarp of western Colorado were carried north and northwest across a stable but slowly subsiding plain. It is mainly sediments from these southern and southeastern sources, rather than coarser lithic fragments from the Sevier highlands to the west, that form the Colton Formation. With time Lake Flagstaff diminished in size and was displaced westward by the dominant sediment inflow from the south and southeast.

Downwarping of the depositional basins was ongoing, but rates of subsidence may have varied (Ryder and others 1976). The lacustrine environment expanded outward again, and Lake Uinta and Lake Gosiute were formed. Flagstaff Limestone is typically overlain by Colton Formation (fig. 26), but between Soldier Summit and Thistle the Colton changes westward by gradation and intertonguing into white and gray shale, sandstone, and limestone of the Green River Formation that lie directly on Flagstaff Limestone (Spieker 1946). Similar relationships are seen in the western Wasatch Plateau and Gunnison Plateau (Spieker 1946). Fouch (1975) identified Flagstaff Limestone in the subsurface of the center of the Uinta Basin at Duchesne and Altamont oil fields, and determined Flagstaff–Green River lacustrine deposition was uninterrupted in this area also. There are, therefore, several areas where lacustrine deposition was not interrupted by Colton subaerial deposition.

The Colton–Flagstaff boundary is sharply defined between Colton and Willow Creek. Between Willow Creek and Sunnyside the Flagstaff and Colton intertongue, with a calcareous zone containing a few well-defined limestone beds persisting as far east as Sunnyside (Spieker 1946, p. 140). East of Sunnyside the Colton lies directly on North Horn Formation, perhaps disconformably (Spieker 1946). Wherever the Flagstaff is missing, the tendency is to identify the combined Colton and North Horn Formations as Wasatch Formation (fig. 26).

The Colton–Green River contact is regular and easily recognizable from Soldier Summit eastward to the upper reaches of Minnie Maud Creek. Eastward from Minnie Maud Creek the Colton thickens upward and the overlying Green River Formation intertongues with it (Spieker 1946, p. 140). Bradley (1931) identified a tongue of the Colton (Wasatch) in the Green River Formation in his "Indian Canyon" section, the base of which was measured along Willow Creek in Emma Park. Spieker (1946) didn't mention this tongue at his type locality at Colton, but Moussa (1969) identified it at Soldier Summit and proposed that it be called the Tabbyune Creek Tongue of the Colton Formation (fig. 26). Based on Moussa's (1965) description of poor or limited exposures, the Tabbyune Creek Tongue has lost much of its typical Colton characteristics in the area north of Soldier Summit and probably grades into Green River Formation in the same general manner and same general area as the main body of the Colton Formation (fig. 26).

Middle Fork Tongue of the Green River Formation is the name Moussa (1969) proposed for the lacustrine facies beds separating the Tabbyune Creek Tongue from the main part of the Colton Formation (fig. 26). The Middle Fork Tongue grades and interfingers into the Colton Formation near Sunnyside, Utah (Hendel 1957; Abbott 1957).

The Soldier Summit Member of the Green River Formation, which Bradley (1931) called the "second lacustrine phase of Green River formation," overlies the Tabbyune Creek Tongue (Moussa 1969).

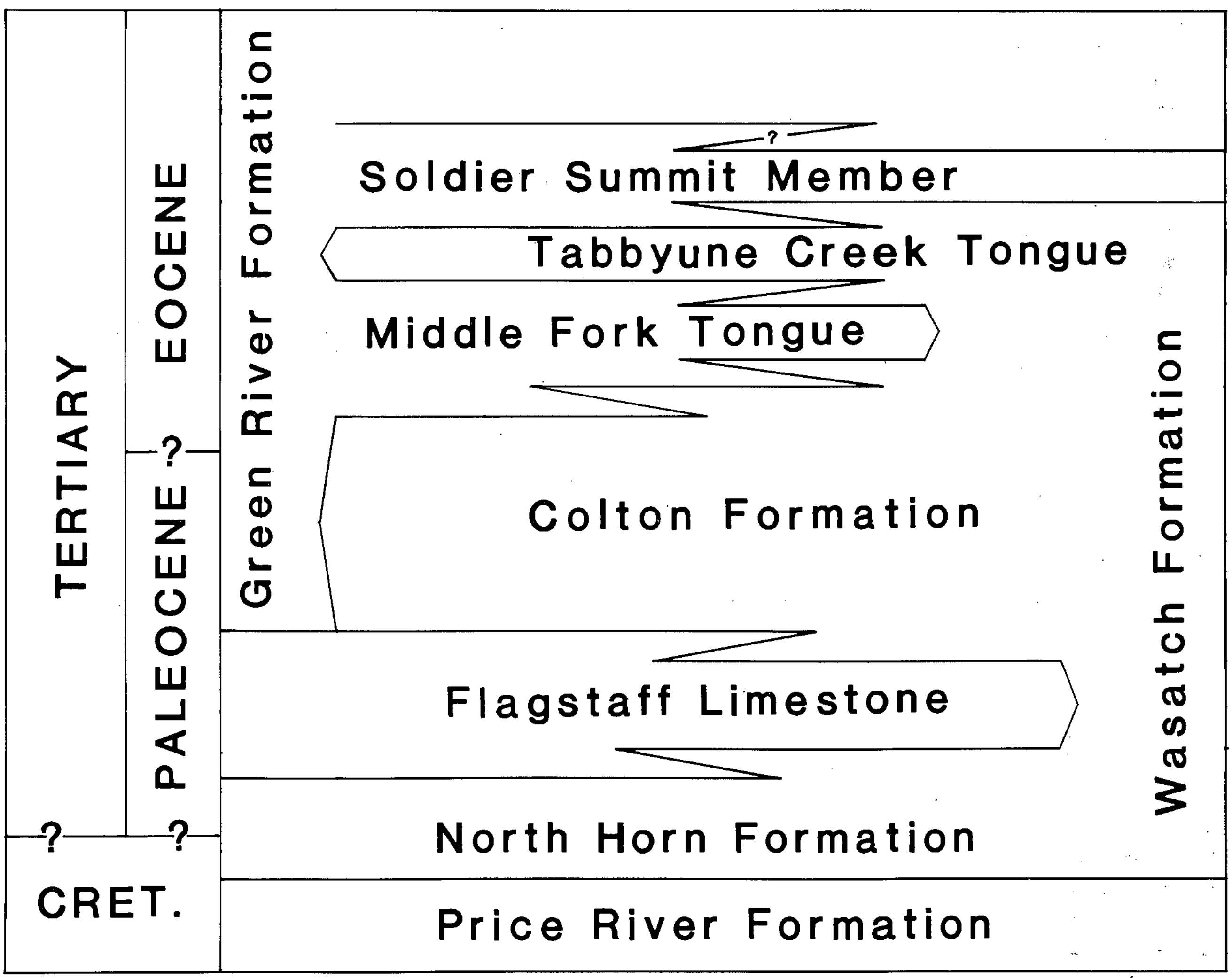

FIGURE 26.—*Generalized stratigraphic section of Emma Park area.*

Boundaries between the Middle Fork Tongue, Tabbyune Creek Tongue, and Soldier Summit Member are not well exposed in the area studied, but the general rock types can be recognized, based largely on color.

Recognition of intertonguing is important in establishing the Colton–Green River boundary. Intertonguing similar to that in Emma Park was noted in outcrops east of Emma Park (Spieker 1946) and in southwest Wyoming (Bradley 1964), and has been identified in the subsurface of the Uinta Basin (Picard 1957). Picard (1957) placed the base of the Green River Formation at the first red shale. Roberts (1964) placed this boundary at the lowermost ostracodal limestone, or lowest ostracod occurrence in some cases. Bradley (1931) and Moussa (1965) placed the base of the Green River Formation at the lowest paper shale.

Spieker (1946, p. 139) determined the Colton Formation to be possibly Wasatch in age, in the lower Eocene. Newman (1974) placed the Paleocene-Eocene boundary at the base of the Colton Formation. Ryder and others (1976) have supported placement of the Paleocene-Eocene boundary within the upper one-third of the Colton Formation on the south side of the Uinta Basin and near the top of the Flagstaff Limestone on the north side of the basin.

PALEOGEOGRAPHY AND REGIONAL SETTING

Intermontane lakes provide probably the best modern models of the early Tertiary lakes of the Rocky Mountain area. Hyne and others (1979) studied the Catatumbo delta in Lake Maracaibo for this reason. Bradley (1931) used Goose Lake on the Oregon-California border as a possible model. The Great Salt Lake, in Utah, is in many respects a good model, although its salinity produces evaporite deposits that are not related to the deposits in Emma Park. Lake Maracaibo is the only one of these lakes that approaches the areal extent of Lake Uinta, about 20,000 km^2, as figured by Picard and High (1972).

Coleman (1981) presented the following factors for consideration in analyzing delta deposits: climate, water discharge regime, sediment yield, river mouth processes, wave power, tidal processes, wind processes, nearshore currents, shelf slope (for this study, basin slope), tectonics of receiving basin, and receiving basin geometry. An additional major factor in lake basins is changes in water level. Details of these factors as they influenced deposition of the Colton delta are not known, but previous studies, along with the present study, can provide a good idea of how these factors may have interacted to influence deposition of Flagstaff, Colton, and Green River sediments.

RECEIVING BASIN GEOMETRY

The bottom of Lake Flagstaff–Lake Uinta may have been relatively steep on the west and north sides adjacent to the highlands, but the eastern shoreline and lake bottom had a very low slope (La Rocque, 1960), approaching 20 cm/km (1 ft/mile) as estimated by Bradley (1931). This is similar to the 20 to 100 cm/km slope of the Great Salt Lake and to the 60 cm/km of the Mississippi delta (Coleman 1981). Maximum depth was about 30 m (Bradley 1931). Exposures in Emma Park show that mud and silt were the dominant clastic materials, with some fine-grained sandstone. Bottom configuration would have been smoothed by deposition of fine-grained clastics and lacustrine carbonates. The Flagstaff basin was generally elongate from north to south and evolved into a more east–west basin in Lake Uinta time (Stanley and Collinson 1979).

CLIMATE

Bradley (1929) summarized earlier documentation on the climate of the Green River lakes and concluded that the climate was characterized by cool, moist winters and relatively long, warm summers. Bradley (1929) also cited the conclusion that floras were similar to those now living in the region from South Carolina to Louisiana of the South Atlantic and Gulf States. Murany (1964) determined that the Wasatch (Colton of present study) was deposited in a climate similar to that of the modern tropics, typified by a rainy winter season and a hot, dry summer season when streams may have dried entirely. Baer (1969) identified plant fossils indicating a subtropical climate.

Leopold and MacGinitie (1972) found palynological and fossil plant evidence indicating a subtropical climate for the early and middle Eocene deposits in Utah, Wyoming, and Colorado. This would mean mild frosts, but with an average temperature of 6° to 18° C in the coldest month. Broadleafed evergreens and temperate climate plants grew together. Early to middle Eocene climate and flora were comparable to those of modern southeast China and southern Japan. Summer and winter both experienced rainfall, but there was a time in earliest middle Eocene when the climate became seasonably dry.

WAVE POWER

Lake Uinta lay at about the same latitude as the present deposits, in the zone of westerly winds. La Rocque (1960) presented ripple marks in Flagstaff deposits as evidence of the lake's overall shallowness, bottom sediments having been reworked by waves in areas far from shore. The oncolites documented in this present study also indicate times of moderate wave energy in the Tertiary lakes.

Waves can produce significant modification of deltaic deposits, but wave energy arriving at the coastline is subject to several factors. The relatively short fetch across the surface of lakes Flagstaff and Uinta would have limited the energy transmitted into waves in the first place. Low offshore gradient greatly reduces the power that waves can deliver along a shoreline (Coleman 1981). Lake Uinta's low bottom gradient and overall shallowness would have worked to attenuate any wave energy generated.

The Mississippi delta has low wave energy along its coastline, which is highly indented and marshy and has scarce, poorly developed sand beaches (Coleman 1981). Wave energy on the Catatumbo delta is low. The delta plain is covered by swamps and ponds. Sand is carried from the north by littoral drift, and sand beaches, spits, and barrier islands (Hyne and others 1979) produce a relatively straight coastline. The Colton shoreline was probably irregular and lacked sand beaches, as does the Mississippi delta. There are no thick sandstone bodies associated with the lacustrine to deltaic transition zone deposits, and sandstone forms a minor portion of the total rock sequence. Sandstones in the transitional deposits are thin in both Emma Park and to the west where Peterson (1976) described delta front and distributary channel deposits.

TIDAL PROCESSES

Astronomical tides caused by gravitational attraction of the sun and moon can be a major source of erosional and depositional energy in marine basins. Such tides on lakes have not been extensively studied, but they appear to be minor (Hutchinson, 1957, p. 333–334). Redfield (1961, cited in Hyne and others 1979) measured a tide of 6 cm in southern Lake Maracaibo. Regular diurnal or semidiurnal movement of water by tides on lakes is minor, even with low shoreline gradients such as on modern Great Salt Lake or on ancient Lake Uinta. Since the lower deltaic plain lies between low and high tide limits (Coleman 1981), this environment is limited on lacustrine deltas if only astronomical tides are considered.

WIND PROCESSES

Wind tide, also called forced seiche, denivelation, or setup-setdown, occurs less frequently and without the regularity of astronomical tides, but flooding or subaerial exposure along lake coastlines is a common result of this phenomenon. Initial displacement of the water surface from equilibrium is the result of wind stress across the water surface, atmospheric pressure gradient across the surface, or a combination of both. When wind stress is physically moving the water as a current across the surface, a countercurrent will develop along the bottom or lake shore and an equilibrium may be reached with the lake surface tilted out of level (Hutchinson 1957, p. 265).

Oscillatory motion, seiche, or free seiche may continue for an extended period once the cause of the initial disturbance is removed. Flooding and exposure of coastline and flow of countercurrents occur, but the magnitude of these phenomena decreases, usually rapidly. Earthquakes also can produce seiches.

Height of initial displacement and the period and duration of seiching are dependent on surface area, depth of water, bottom configuration, and basin shape and its relationship to wind direction (Hutchinson 1957.) Lake Flagstaff and Lake Uinta lay in the zone of westerly trade winds. The Flagstaff basin was generally elongate north to south and evolved into a more east-to-west basin in Lake Uinta time (Stanley and Collinson 1979). Wind tide and seiching are usually dominant along the long axis of a body of water, but also occur transverse to the long axis (Hutchinson 1957). The Colton delta was, therefore, located where wind tides could have produced flooding and exposure of the shoreline and produced countercurrents along the bottom or along the shore.

It is difficult to model the effect of bottom configuration, gradient, and water depth and, for the purposes of this study, it is proposed that typical wind tides along the Colton shoreline were similar to those of the Great Salt Lake today. The Great Salt Lake, in Utah, lies with its long axis transverse to the westerly winds. Documented wind ties there have raised or lowered the surface as much as 20 to 25 cm from equilibrium (Lin 1976, fig. 6) and occur 10 to 20 times a month (Lin 1976). On the Great Salt Lake, wind tides and storm waves together can affect the shoreline at least 1 m above lake level (Elmer in press). Wind tides and seiches of around 2 m have been recorded on the Great Lakes and other lakes, but judging from data presented by Hutchinson (1957) a normal range for wind tides would be 20 to 25 cm.

In the stratigraphic record wind tides may produce deposits similar to astronomical tides. Laguna Madre, Texas, is surrounded by mud flats deposited when wind tides force water over them (Miller 1975). The principle deltas into the Great Salt Lake are dominated by extensive mud flats, probably produced, at least in part, by wind tides. Much of the dominant clay and silt sediments that Colton rivers carried into the lakes would have been held in suspension long enough to be transported onto nearby mud flats by wind tides and deposited there.

NEARSHORE CURRENTS

Winds would have aided the distribution of fine sediments away from the distributary mouth by creating littoral currents. Locally generated waves would have also helped keep these particles suspended, and wind tide countercurrents could also have suspended fine sediment and reworked coarser sizes. Hyne and others (1979) found sediments, finer than the sediments of the open lacustrine environment, in a thick lens where littoral drift had carried them south from the effluent of the distributaries of the Catatumbo.

BASIN SLOPE

The low offshore gradient of the Colton coastline was important not only as a control of wave power and wind tides, but Coleman (1981) also found that a low gradient, low wave, and low tide power basin produced lateral migration of the entire deltaic lobe, such as occurred on the shoal water lobes of the Mississippi (Kolb and Van Lopik 1966), as opposed to migration of a single channel.

TECTONICS OF RECEIVING BASIN

The basin containing Lake Flagstaff–Lake Uinta was subsiding, as evidenced by the thickness of both lacustrine deposits and marginal deposits such as the Colton Formation. Changes in lake level would have been interacting with subsidence of the lake basin. Importantly, since the lake was in a closed basin, not only overall tectonics but intrabasinal tectonism localized to one part of the lake basin could have affected the relative water level in all parts of the lake.

Subsidence of the basin into which the Colton delta prograded not only produced the great thickness of deltaic sediments, but, as Fisher and McGowen (1969) indicated, in a subsiding basin there may be an incomplete succession of facies in vertical section. This appears to be the case in the Colton deposits.

WATER LEVEL CHANGES

The surface area of Lake Flagstaff–Lake Uinta was probably variable. Bradley (1931) proposed that the lake was stable only when its elevation became high enough to overflow, as Oregon's Goose Lake does today. Otherwise the level varied greatly. At times the lake may have been no more than a series of ponds and marshes.

The Great Salt Lake, Utah, which now fills the bottom of a relatively flat, closed basin, undergoes several cycles of level change. Most common is the annual fluctuation, typically 30 to 60 cm (Elmer in press), due to the annual climatic cycle. If Lake Uinta and its drainage basin were subject to wet-dry seasons, Lake Uinta probably underwent a similar rise and fall annually, although the amount is unknown. Longer-period lake level cycles of 11, 22, 45 to 50, 90, and 180 years have been identified for the Great Salt Lake based on hydrographs and on historical accounts (Elmer in press). The level of the Great Salt Lake has varied 6 m within historic time. A rise of 1 m from 1962 to 1972 almost doubled the surface area and volume of the lake (Lin 1976). During these level changes the shoreline has moved several kilometers where gradients are low, and thousands of square kilometers of surface have been flooded, or exposed when waters receded again.

Bradley (1929) identified two cycles in the Green River deposits, an 11-year sun spot cycle and a 22,000-year cycle related to precession of the equinoxes. Other lake level cycles are not known. The large size of the Tertiary lakes and the semitropical climate would be two important factors that may have reduced short-term level fluctuations in comparison to the Great Salt Lake or other modern closed lakes.

The general pattern of short-duration wind tides, annual level changes, and longer-period level fluctuations would have been major influences on sedimentation along the shores of the Tertiary lakes, especially the low gradient surface of the Colton deltaic plain. In ways this environment may have resembled the lower deltaic plain of marine basin deltas, but the irregularity and relative infrequency of flood and subaerial exposure cycles would have allowed the low-power waves and littoral currents adequate time to rework sedimentary structures formed by the rising and falling water. Mud flats such as those found around the Great Salt Lake's major deltas and Laguna Madre may have been the feature most analogous to a coastline with astronomical tides.

WATER DISCHARGE REGIME

Coleman (1981) related nonerratic fluvial discharge to meandering. The Colton rivers obviously meandered and were probably nonerratic in the sense of having a seasonal high flood and low but regular flow the rest of the year. Mud cracks are not prominent in Colton rocks in Emma Park. Rooting and burrowing may have erased them from the stratigraphic record, but in deposits along the Niger River, which has the type of discharge regime just described, desiccation features are not seen because humidity in the air maintains ground moisture during times of low river flow (Allen 1965b).

SEDIMENT YIELD

Sand is prominent in the large Colton point-bar lenses, but the volume is minor when compared to the vast mud and silt of the overbank deposits. Large volumes of sand were moved and deposited during floods, but a suspended load of mud and silt was the major sediment of the deltaic plain and also would have dominated the subaqueous delta and adjacent shoreline.

RIVER MOUTH PROCESSES

The relationship between water of the Flagstaff–Green River lake and of the Colton river as it would affect river-mouth processes is not known. The river was fresh water, its density increased by suspended load. The lake was not hypersaline at Colton time; it was fresh but contained calcium and other elements in solution (Stanley and Collinson 1979). Densities of the two waters were probably close and frictional processes would have dominated as they do on the Catatumbo delta (Hyne and others 1979). Using Coleman's (1981) model of river-mouth processes, a radial bar probably would have formed due to the lack of buoyancy of the river water and the low gradient of the basin. Sediment would have been widely scattered, but well sorted.

INTERPRETATION

The sandstone lenses of the Colton Formation in Emma Park were deposited in meandering fluvial channels on the deltaic and alluvial plain of the Colton river or rivers. Clastic sheet deposits were laid down as overbank deposits, mainly on the levees' flanking channels. The mudstone that encloses the sandstone lenses and sheets was deposited mainly in floodbasins beyond the levees. The Colton deposits agree closely with current models of fluvial-deltaic deposition, such as those proposed by Harms and others (1963), Allen (1965a), Visher (1965), Harms and Fahnestock (1965), Potter (1967), and McGowen and Garner (1970). Fisher and Brown (1972) gave several models for deposition that seem particularly suited for interpreting the Colton deposits.

FLUVIAL-DELTAIC SYSTEM

The lenticular, asymmetrical, imbricate composite sets that form the sandstone lenses of the Colton Formation are point-bar deposits, the result of bed-load deposition on the inner, convex bank of a meander loop during a period of flooding. Erosion of the cutbank on the outer, concave bank of the channel, accompanied by lateral accretion of the point-bar deposits, produced the flat-topped, tabular-appearing lenses.

Unit 3 of section 1 is topped by a symmetrical lenticular coset that is slightly concave on the top. This is a channel-fill deposit of bed-load sediment, probably the result of chute cutoff, similar to the model presented by Allen (1965a). This is the only identifiable channel-fill deposit observed in Emma Park.

Scour from the cutbank and channel bottom introduced mudstone pebbles that were laid down in channel-lag deposits along the channel bottom. These were rapidly rounded and represent the coarsest material in the Colton system in Emma Park.

The principle load of the Colton stream was fine sand transported in bed load and silt and clay carried in suspension. Following the model of Harms and Fahnestock (1964), the sand usually formed large ripples or dunes as it was moved along the bottom. These dunes were preserved when they filled scours on the channel bottom and were overlain by the next sequence of dunes. They are now seen as trough-shaped sets of cross-strata that are the dominant sedimentary structure in the sandstone lenses.

Fluctuations in stream discharge and variations of channel geometry, as the point bar accumulated, produced changes in water velocity. These various velocities resulted in deposition of small ripples and horizontal laminations on the point bars, similar to those described by Harms and Fahnestock (1964) and horizontal strata in the channel deeps such as Allen (1965a) proposed in his model.

Floods carried sediment out of the channel, onto the levee, and into the floodbasin. Velocity dropped as water spread over the levee crest, energy dissipated rapidly, and successively finer and finer sediments were deposited down the levee slope. Root marks indicate plants were abundant on the levees and helped slow the water, in a manner similar to that noted by Hyne and others (1979) and Coleman and others (1964) on levees of modern rivers. Ledge-forming sheet deposits in the Colton Formation, which are cross-stratified and burrowed, match the descriptions and illustrations of modern levee deposits given by Allen (1965a, 1965b). Interstratification of sheets of silt and sand with mud are one of the characteristic features of levee deposits according to Allen (1965a, p. 146). In these Colton strata, as in other levee deposits, coarser sediment represents the rise of the flood and mud the recess. Probably many sheet deposits were similarly deposited in the floodbasins when floods carried silt and fine sand beyond the levees in a manner such as Allen (1965a, p. 146) has described on modern deltas.

Bernard and Major (1963) and Visher (1965) remarked that sediments and sedimentary structures of levees can be very similar to those of the upper point bar and that the two depositional environments are difficult to distinguish. Fisher and Brown (1972) pointed out that in meandering fluvial deposition, levee deposits often overlie channel deposits. Platy splitting, horizontal or rippled cross-stratified sandstone overlying or adjacent to sandstone lenses in Emma Park may represent deposition either on the upper point bar or near the crest of the levee where velocities were high enough to transport bed load.

Levees and presence of mud drapes between sandstone strata sets and cosets in sandstones of the Colton Formation in Emma Park support the models of periodic variation of stream flow, such as those of Bradley (1929), Murany (1964), and Leopold and MacGinitie (1972), with alternating flood and low stages rather than a steady level of flow. Complete drying appears to have been rare.

Finest sediment settled out in relatively quiet water in the floodbasin. Plant roots and burrowing organisms reworked these sediments almost continuously and destroyed most of the sedimentary structures, similar to what occurs in floodbasins of the Mississippi and Niger rivers today (Coleman and others 1964; Allen 1965b). Plants and animals also lived on the levees, at least partly mixing the sediments there, and between floods the plants invaded exposed parts of the point bar in a manner similar to that described by Allen (1965b) on the Niger River and Hyne and others (1979) along the banks of the Catatumbo River.

The dominant red coloration of these Colton deposits indicates they were well drained and that floods were of a frequency and magnitude that allowed thorough oxidation of nearly all sediments deposited. Local low spots developed temporarily where some reduction occurred in stagnant water. Ryder and others (1976) have attributed reduced mudstone found beneath some channel sandstones to downward migration of chemically reducing water from the channel, supposedly by secondary fluids migrating through the sandstone.

Thickness of point bars indicates depth of water in the channel during flood stages (Allen 1965a, p. 138). Most of the sandstone lenses in Emma Park have covered basal contacts and still have 3 to 10 m of point-bar deposit sandstone exposed. Lenses with exposed basal contacts, such as units 35 and 36 of section 8, have thicknesses between 5 and 10 m. Unit 1 of section 2 is the thickest single-story lens measured at 16.5 m, and the base is not exposed (fig. 25).

The thickest sandstone lens reported by Peterson (1976) in Colton exposures to the west is 3.5 m. Comparison between Colton sandstone lenses in Emma Park and Peterson's area shows that lenses are generally thicker and broader in Emma Park, especially those that are exposed on the north slopes in the upper part of the formation.

Based on exposures of the Colton Formation between Colton and the head of Price Canyon, Peterson (1976) interpreted the Colton sandstone bodies as mainly delta front and distributary channel deposits. He identified only a few localized point-bar deposits. Direction of sediment transport was dominantly northward (Peterson 1976). Colton sandstones in Emma Park are thick point-bar and levee deposits, formed by meandering rivers on the deltaic plain. Direction of sediment transport is dominantly northwest (fig. 2).

PHASES OF DELTA

Deltas are continuously changing features of the landscape, and Fisher and Brown (1972) have broken deltaic deposition into two phases: constructional and destructional.

Constructional Phase of the Colton Delta

A red mudstone unit at least 30 m thick is partially exposed just east of the bridge over the Price River at Kyune, in section 32, T. 11 S, R. 9 E, near the junction of the county road with U.S. 6-50. The red mudstone underlies oncolite-bearing limestone and gray mudstone that are laterally equivalent to units exposed nearby at the base of measured section 12. Aerial photos show this red mudstone thins eastward. It forms the broad valley floor south of the road at Matts Summit. It is 24 m thick as unit 9 of measured section 9, and is underlain and overlain by gray lacustrine limestones. Red and brown sandstone and mudstone units, totaling less than 10 m in thickness, are interfingered with limestone and gray mudstones and shales at the base of the Colton Formation in the eastern part of the study area at measured section 10 (plate 1).

This tongue of red mudstone represents the distal part of a delta that intruded into Lake Flagstaff (fig. 27A). The main part of this delta apparently lay to the west and was a salient from the southeastern shore of Lake Flagstaff. The exposure in Emma Park represents a lobe that formed an embayment between itself and the main shoreline. The bays flanking the river on the Catatumbo delta might be a modern example of this type of embayment (fig. 28). Interfingered lacustrine and fluvial-deltaic deposits of units 1–13 of section 10 indicate the shoreline of the delta and embayment and the environments that existed there over a period of time.

Fossiliferous lime packstone, unit 10 of section 10, was deposited in quiet water, probably near shore or in a bay, in shallow water where there was little motion to disturb the sediments. *Hydrobia* shells in this unit are unbroken, unabraded, and unoriented. Lime mud usually is found only in the first whorl, indicating the shells were virtually undisturbed after the snail died and the shells accumulated on the bottom.

The middle of this unit shows a facies with little lime mud but with abundant plant material, snail shells, and ostracod valves, which were compacted by later overlying sediments. Algae formed thin, fragile structures that were broken and deformed during compaction of the deposit (fig. 21). This middle facies is interpreted to represent an environment such as Baer (1969) described in Green River Formation deposits to the west, with thick plant growth, both rooted and floating in nutrient-rich water. The bottom environment was nonoxidizing and debris was preserved, perhaps in conditions similar to what Bradley (1966) has described in modern subtropical lakes. Algae grew as a loose mat.

Other limestones in measured section 10, such as the thin, fossil-poor units 7 and 11, are similar to Flagstaff limestones exposed at the bottom of measured section 9

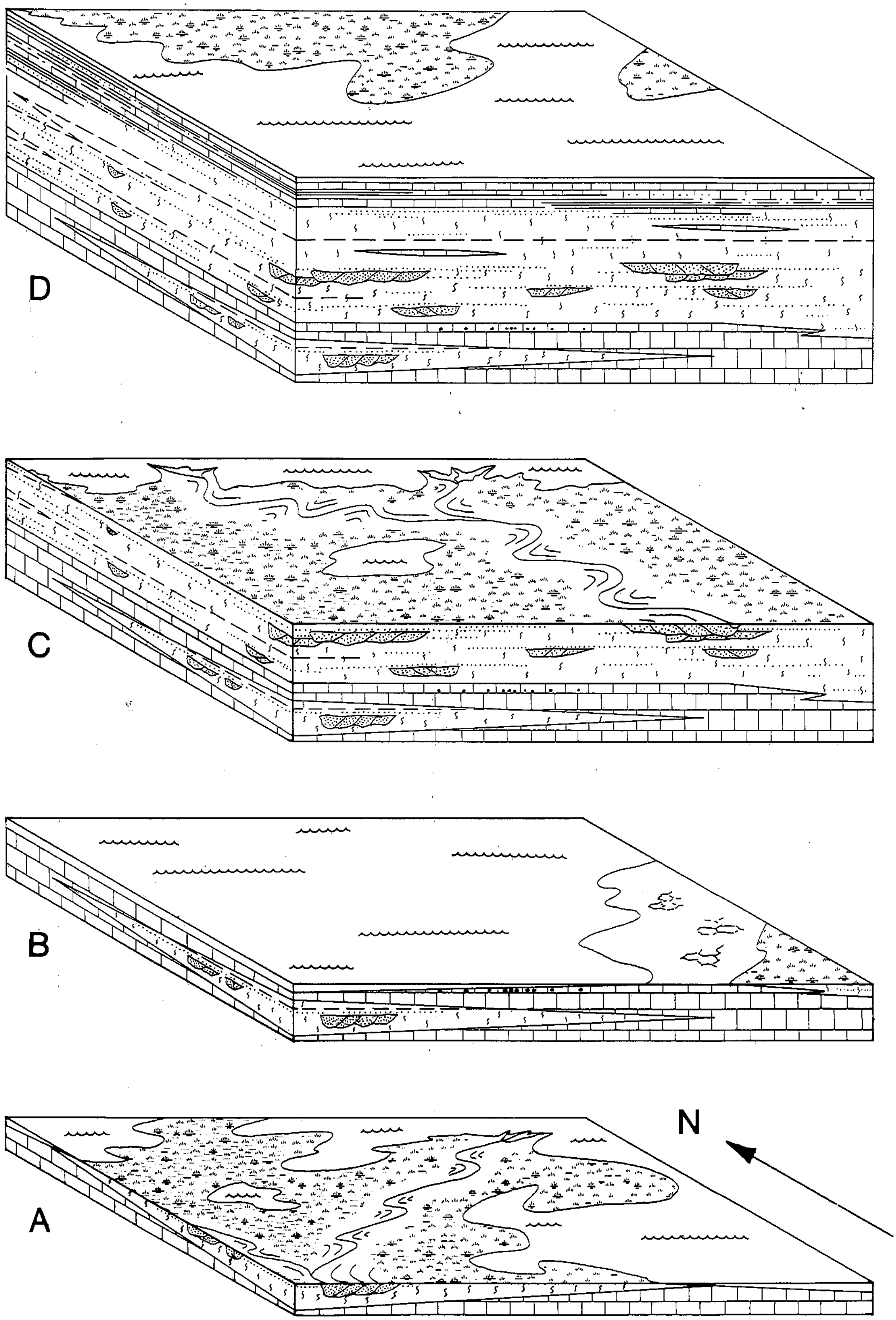

FIGURE 27.—*Emma Park depositional environments. (A) Early encroachment of subaerial delta forming a shallow bay on southeast flank. (B) Return of lacustrine environment, deposition of oncolites. (C) Progradation of main constructive sequence. (D) Destructive delta phase with subsiding surface and submersion of delta plain by marginal environments. Blocks approximately 10 km square with vertical scale greatly exaggerated.*

and may represent periods of more open water and transgression, perhaps periods of rising lake water. Unit 8 contains mudstone rip-up clasts from a period of subaerial dessication and mud-crack formation. Variegated clastic mudstones were deposited in higher energy regimes where sediment influx dominated over carbonate formation. Unit 1, the only sandstone in this sequence, does not clearly indicate depositional environment, but the southerly transport direction opposes that of the overlying Colton sandstone lenses and indicates a local current direction of unknown source.

The main body of Colton red mudstones and sandstone lenses overlies these transitional deposits at the east edge of the area studied, supporting the concept that they were formed in a bay or lagoon partially separated from the main lake body by a deltaic lobe extending beyond the advancing shoreline, then transgressed by the main sequence of subaerial clastic deposition.

Gray mudstone and oncolite-bearing fossiliferous lime packstone that overlie the red deltaic tongue in the central and western parts of the study area represent a period of lacustrine transgression in western Emma Park that should grade eastward into the upper part of the transitional bay and shoreline facies discussed above. Transgression of lake waters probably resulted when the stream that had formed the delta abandoned the local channel to follow another, more advantageous route to the lake. With reduction of clastic inflow, compaction of sediments by gravity and dewatering produced a subsiding surface similar to that described by Gould (1970) for shoal water lobes of the Mississippi delta. The lake expanded onto the abandoned delta as the surface lowered. Locally the delta consisted mainly of red mudstone deposited in marshes and mudflats away from large stream channels. Little sandstone was observed within this lowest mudstone tongue, so sand was not abundant locally to form delta front sands, such as those described by Peterson (1976) in Colton deposits to the west, nor to be reworked by the transgressive lake waters into beaches or other shoreline features.

Gray mudstone separating the red mudstone from the overlying lacustrine limestone at Kyune is interpreted as prodelta deposits. Subaerial deposition ceased locally, but the active delta remained near enough to supply fine sediment to the slowly submerging surface. Hyne and others (1979) found the finest sediment in Lake Maracaibo in clastic prodelta deposits near the distributaries in the downcurrent direction.

Continued subsidence, plus possible further avulsion of the stream, finally introduced deeper open lake waters to the Emma Park area. Carbonate deposition dominated over clastic influx (fig. 27B). Oncolites in the transgressive lacustrine strata indicate the water was less than 2 m deep and continuously agitated, most probably by waves, following a model proposed by Logan and others (1964). The largest oncolites are found near Matts Summit at the bottom of measured section 5, which indicates the zone where normal wave base intersected the bottom and continuous agitation was greatest. Oncolites near the bottom of measured section 11, to the west, and at the top of measured section 9, to the east of Matts Summit, are noticeably smaller and less abundant than those near Matts Summit. Rip-up clasts are abundant and often relatively large in this unit, eastward from Matts Summit. This indicates that shoreline mudflats and shallow water deposits to the east, such as unit 8 of section 10, were being exposed, dried, and cracked. These cracked blocks were then either transported short distances by storms or deposited in situ as intraformational conglomerates when the lake transgressed across the area.

Point-bar, levee, and red floodplain deposits accumulated on top of the lacustrine limestone and mark renewal of active deltaic deposition in the area (fig. 27C). There are no multiple-sheet sandstones or straight channel distributaries such as those described by Peterson (1976) in the Colton Formation and attributed to delta front and distributary environments. There are a few thin, poorly exposed gray green mudstones in the lowermost Colton that possibly represent prodelta deposits of this new deltaic progradation.

Sandstone lenses are noticeably less abundant in the lower Colton beds of the valley floor in Emma Park than in upper units on the slopes of the north side. Just as with the lower red mudstone tongue, there was little sand available locally to form delta fringe structures. At Kyune, at the west edge of the study area, a large sandstone lens lies approximately 20 m above the lacustrine limestone. A sheet sandstone lies beneath the lens and may be a thin delta front sand laid down as this channel prograded into this western part of the area.

Sparsity of transitional lacustrine to deltaic deposits across most of Emma Park suggests relatively rapid withdrawal of the lake, accompanied by prograding fluvial-deltaic deposition. Tectonism is one possible explanation for so abrupt a shift of shoreline. Fisher and McGowen (1969) suggested that deposits in a subsiding basin should have an incomplete vertical succession of facies. The absence of prodelta and distributary facies in Emma Park may be the result of the subsidence of the basin, along with avulsion of the major regional stream into the area and resulting delta progradation. This renewal of subaerial deposition continued the progradation of terrigenous deposition from the southeast that had been presaged by the basal red mudstone and interrupted by the lacustrine phase.

There is another possible explanation for the absence of distributary and delta front facies between lacustrine limestone and delta plain deposits in Emma Park. Ferm

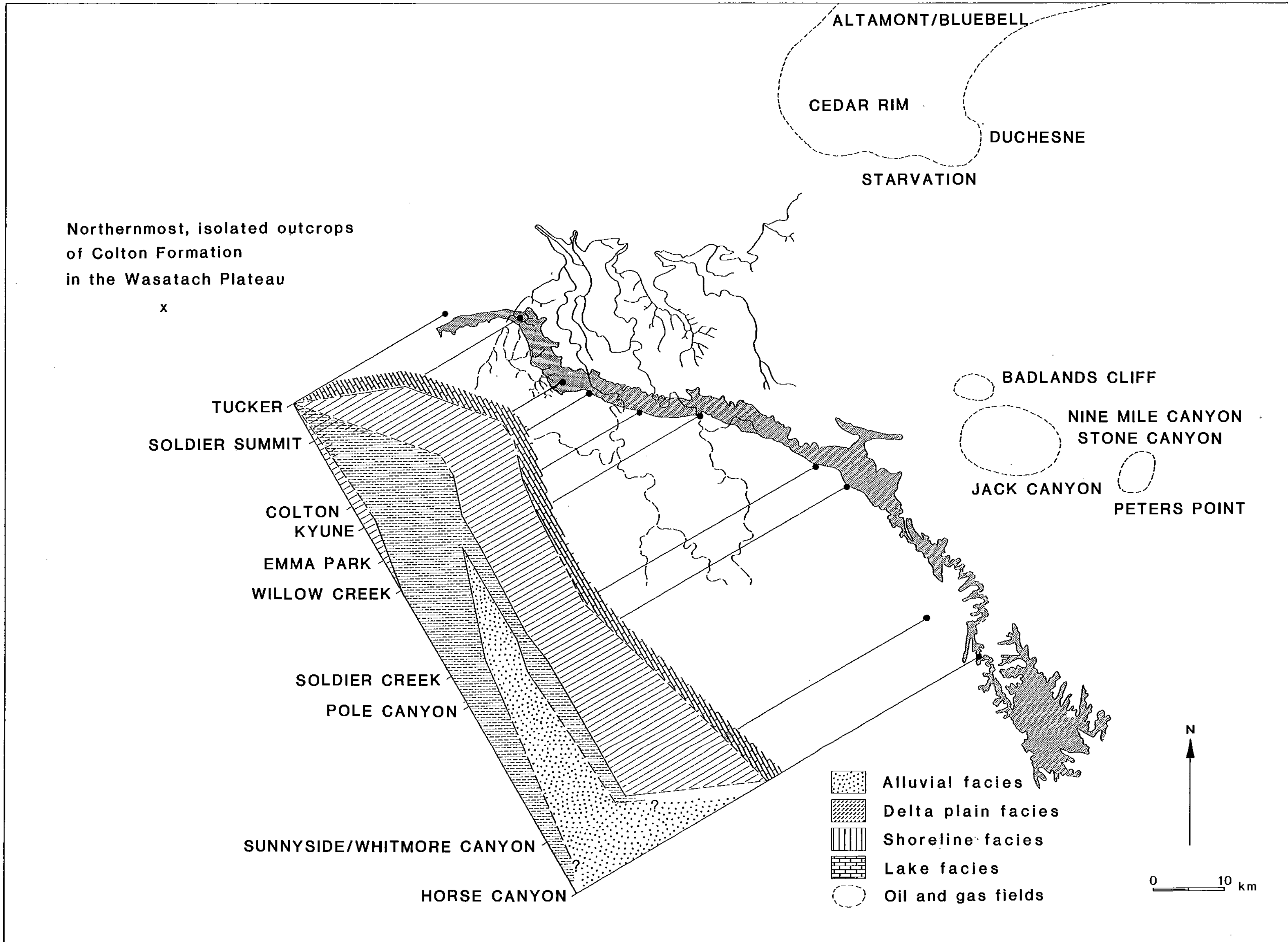

FIGURE 28.—*Projection of Catatumbo delta onto Colton outcrop, representing farthest advance of Colton delta into Lake Uinta. Diagrammatic cross section shows locations, general thicknesses, and succession of depositional environments between Sunnyside and Tucker.*

(1974) observed that there was no identifiable delta front facies between the marine and delta plain facies in many exposures of Carboniferous rocks of the southeastern United States. He interpreted the red clastic on marine limestone relationship to indicate free circulation of oxygenated waters between the prodelta and delta plain, unhindered by barrier islands or bars, allowing oxidized sediments to be readily transported to the prodelta environment and eliminating reducing environments from the delta plain. Ferm also inferred that the lack of barriers indicated a lack of wave energy along the coast, which would fit the present model.

Channel deposits of the lower Colton are single storied and show one direction of migration. Levee deposits lie lateral to and extend over portions of the point-bar lenses. Baganz and others (1975) described Carboniferous sandstone lenses up to 12 m deep by 180 m across, about the same size scale as Colton lenses in Emma Park. The migration of these Carboniferous lenses was restricted by cohesive fine-grained overbank deposits through which the channel was eroding (Horne and others 1978), producing isolated lenses rather than broad multilateral units. Kolb and Van Lopik (1966) described the distributaries of the Mississippi delta as migrating little, on the order of 5 to 10 m per year; because of the cohesive fine-grained material they must erode to move laterally. The fine-grained deposits that dominate lower Colton deposits in Emma Park probably limited lateral migration of the Colton streams in a similar manner.

The Niger and Danube Rivers divide into lengthy meandering distributaries before entering relatively narrow lower deltaic plain environments (Wright and Coleman 1973). The Catatumbo splits into at least three lengthy meandering distributaries (fig. 28). Coleman (1981) identified high subsidence rate, low wave action, small tidal range, low offshore slope, and finer grained sediment load as factors favoring development of bifurcating distributaries. All of these conditions were present during Colton deposition and the sandstone lenses of the lower part of the Colton Formation in Emma Park are interpreted as meandering, bifurcating distributaries on a low-gradient deltaic plain.

Crevasse splay deposits are frequently mentioned in models of deltaic-meandering fluvial deposition (e.g., Brown 1973). No crevasse splay deposits were identified in Colton sediments in Emma Park in this study. Hyne and others (1979) found few crevasse splays in the Catatumbo fluvial-deltaic system in comparison to the Mississippi system. Lack of flood tides to impound the river flow and raise the water level, and the stabilization of levees by dense vegetation were seen as the main reasons. There is evidence in the Colton deposits of thick vegetation on the levees and exposed point bars, and regular tidal action was probably insignificant on the Tertiary lakes, so crevasse splay deposits should not be expected to be abundant.

A sequence of gray mudstones are found about halfway up through the Colton section on the west side of Emma Park, in measured section 12. These strata interfinger with the red deltaic mudstones, and thin eastward. These thick gray strata are absent in sections in the eastern part of the study area, but thin, localized deposits of gray mudstone occur throughout the Colton Formation. This interfingering gray mudstone sequence represents an interlude of lacustrine accumulation between periods of deltaic deposition, or perhaps of lake or pond development on the deltaic plain. Lacustrine environments may not have actually invaded the area, but were near enough to inhibit surface and subsurface drainage and to produce stagnant, reducing environments.

The breadth and width of sandstone lenses increases upward through the Colton in Emma Park, but incomplete exposures do not permit meaningful comparisons by measurements. Multistoried stacks of these sandstone lenses also become more common upward in the Colton of Emma Park, the largest one being the prominent ledge, which is unit 7 of measured section 4 and unit 40 of measured section 8, near the top of the section. The fine-grained meander belt model of Brown (1973) has multistoried point-bar sandstones as one of the distinguishing features. Increasing breadth and stacking into multistoried lenses result from increased meandering of the depositing stream. In Emma Park this is interpreted to indicate progradation into the area of an alluvial environment higher on the delta plain, such as Brown (1973) and Horne and others (1978) have described, where overbank muds were not as effective in limiting lateral erosion and above the point of bifurcation so that fewer channels transported the water and sediments (fig. 28). Streams meandered across the same area several times before avulsing to new courses, producing multistoried lenses with opposing meander movement (fig. 27C). Enlargement of the river's drainage basin or increased precipitation could also have produced this effect.

The Colton thickens eastward and is 500 to 600 m thick at Desolation Canyon on the Green River (Spieker 1946). As the Colton thickens eastward, conglomerates become more abundant and polymictic, sand becomes coarser and more abundant in relation to muds, and the dominant red color gives way to more gray, green, and brown (Fisher and others 1960). This indicates increasing alluvial plain-type environments (fig. 28).

The Colton strike valley between Soldier Summit and Whitmore Canyon cuts obliquely across the direction of transport and the body of the Colton delta, so the extent and shape of the delta is not evident. Hyne and others (1979) studied the Catatumbo delta for the purpose of comparison with Tertiary intermountain lake deltas of the

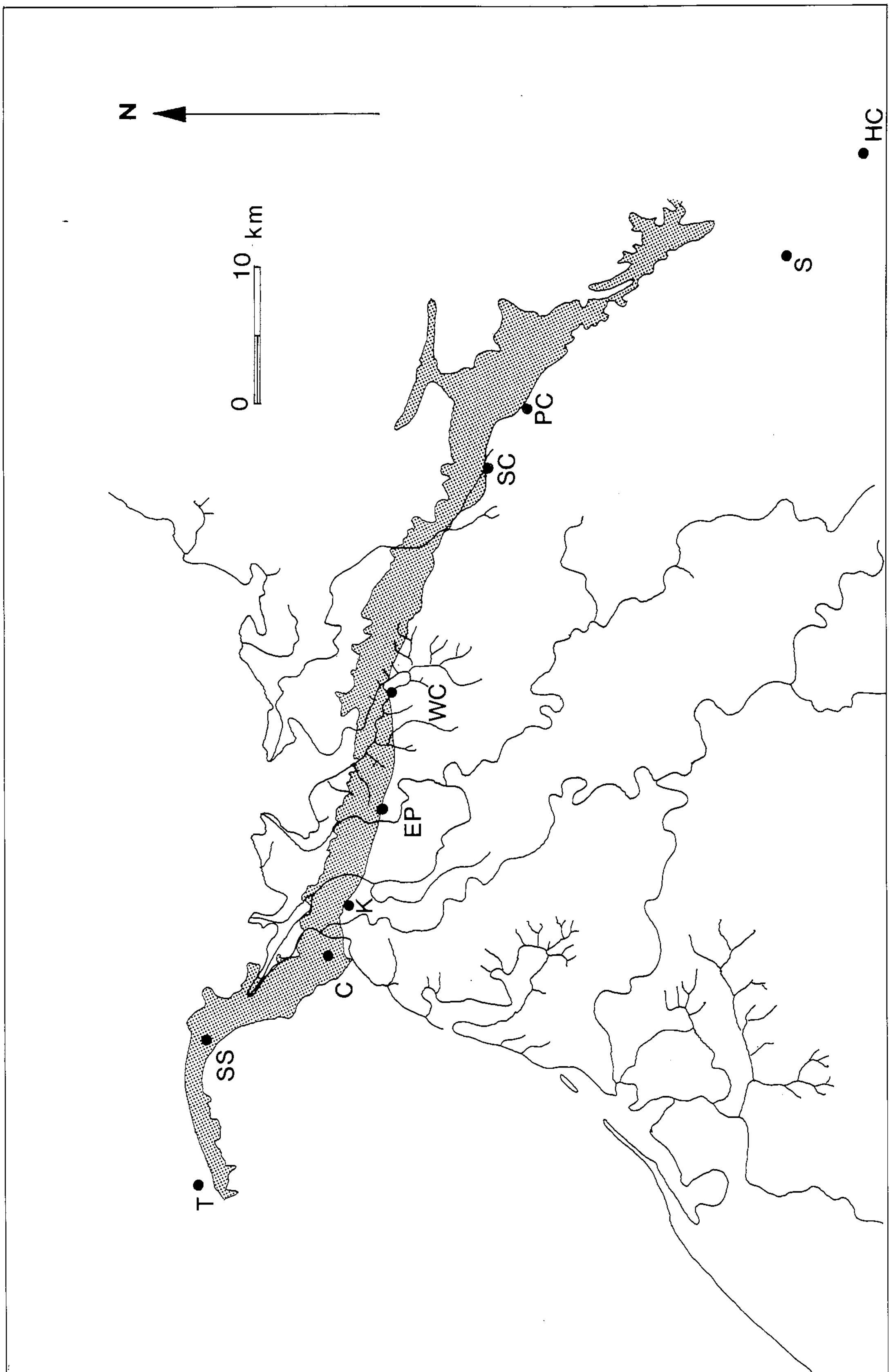

FIGURE 29.—*Projection of Catatumbo delta illustrating possible configuration of earliest delta encroachment into the area. Bay on Catatumbo coincides with bay deposits of measured section 10.*

western United States. If the Catatumbo delta is oriented and projected onto the Colton strike valley so that sediment transport directions line up, a picture of how the Colton delta may have appeared is seen (fig. 29). This particular superposition has the distributary-delta front environments at Colton, where Peterson (1976) described them. An interesting coincidence is the location of the bay or estuary in the vicinity of the Flagstaff-Colton transitional deposits of measured section 10. This model would represent the early entry of the delta into the Emma Park region (fig. 27A).

Destructional Phase

There is not a significant upward decrease in sandstone lens size in the upper parts of the Colton Formation, above the larger multistoried outcrops, comparable to the increase in size upward through the lower part of the formation. This is interpreted as indication that the major delta in Emma Park was abandoned relatively abruptly due to avulsion of the main stream rather than to gradual lacustrine transgression, which would have produced symmetry of deltaic deposits above and below the largest, multistoried sandstones.

Over the past 4000 years the Mississippi delta has undergone several major relocations due to avulsion of the main channel upstream from the distributaries. At present only the U.S. Corps of Engineers is preventing another avulsion of the main channel into the Atchafalaya basin (Gould 1970), a change that could move the distributary system 50 to 200 km west along the Gulf Coast. Not at the same scale as the Mississippi, Colton avulsions probably moved the center of deposition over considerable distances, especially when combined with the generally expansive nature of Lake Uinta as described by Picard (1955). After avulsion, minor streams continued on the deltaic plain, but major deltaic deposition ended abruptly, compaction slowly lowered the surface while the destructive phase of delta development took place as a transgression over the delta.

Waters of Lake Uinta were rich in $CaCO_3$ (Baer 1969), and thin limestones in the upper part of the Colton Formation were deposited when lake waters invaded low parts of the delta as shallow, carbonate-rich ponds or bays that were later filled when red deltaic mud was carried in by floods of local streams (fig. 27D).

The dominant feature of the Colton–Green River boundary, at least from a distance, is the upward, abrupt color change from red to yellowish gray. Measured section 9 through this zone (plate 1), exposed in a deep gully, shows that this color-change zone is marked by interfingering of mudstones of varying colors. Thin limestone beds are also present here and in unit 4 of measured section 3. The color change indicates the transition from well-drained subaerial deposition where oxidation was fairly complete, to poorly drained marginal zones and open waters where reducing chemistry dominated.

Limestones seem more abundant above the last red-hued mudstone, but there is no adequate exposure of the section below the color change to allow true comparison. The limestones are lime mudstone, thin, often silty, and are either unfossiliferous or contain fragments of bivalve shells. These limestones were deposited in ponds, bays, or lagoons that were sheltered from large influxes of sediment. Lack of abundant fossils may indicate these bodies of water were too short-lived to have been colonized, or it may indicate an environment hostile to molluscan life due to chemistry or some other factor.

Sandstone beds such as units 9, 23, and 25 of measured section 11 appear in this transition zone. Sedimentary structures are not preserved in these sandstones. These single-sheet deposits represent another bay, pond, and lagoon facies. Fisher and Brown (1972) indicated such sands could form in small deltas in these bodies of water as marginal shoreface and beach sands. Eolian transport of sediments into these waters could also be important in forming thin clastic deposits. Both clastic and carbonate deposition could occur in different areas of the same system, and the units exposed in measured section 9 indicate that local depositional environments shifted frequently. Baer (1969) found that waters of Lake Uinta were rich in both $CaCO_3$ and fine clastic detritus, and deposition of one or the other was chiefly a function of local energy of the depositing agent. Carbonate deposition was favored in low-energy environments. Growth of algae and evaporation would have favored carbonate deposition in shallow sheltered waters. Baer (1969) identified fine sand and carbonate deposits commonly interfingering in the lagoons of the Green River deltas he studied.

Unit 9 of measured section 1 contains sand mixed with broken and whole *Unio* shells suspended in a lime mud matrix. This unit represents a shallow bay or sound where waves could reach to rework the deltaic sediments, transport the shells, and where conditions existed suitable for deposition of either chemical or organic lacustrine carbonates. Kolb and Van Lopik (1966) found that on the Mississippi delta such a depositional environment is typically separated from the main body of water by a barrier island. Such may have also been the case in the Colton–Green River transition beds, with an exposed part of the old delta forming the barrier (fig. 27D).

Unit 20, measured section 11, is the lowest occurrence of petroliferous shale and indicates an environment of high organic production, similar to what has been decribed for well-known oil shale deposits higher in the Green River Formation (Bradley 1931).

The most widespread facies of the Colton–Green River transition zone is an ostracod lime packstone, the only unit that can be traced laterally between measured sections (plate 1). Rocks of this type are very prominent not only in Emma Park, but are widespread throughout the area of Lake Uinta deposits; for example, see Clair (1952) and Bradley (1964). Roberts (1953) and Swain (1956) have identified ostracods from the Colton and Green River formations and have determined they represent generally shallow pond and littoral environments. Benson (1961), in a general description of freshwater ostracods, stated that they can be very prolific, producing several broods in one season, and that in slightly alkaline, stagnant ponds they are especially prolific and form ostracodal limestone.

Taylor (1972) studied the paleocology of ostracods from the Luman Tongue and Tipton Member of the Green River Formation in Wyoming and concluded that ostracod coquinas represent transported assemblages. However, work done in Pleistocene deposits containing freshwater ostracods indicates that partial reworking of sediments and low-energy levels are sufficient to separate or destroy ostracod valves (DeDekker 1979).

Ostracods in the Colton packstones frequently appear abraded and partially crushed, but the two valves are commonly joined and closed. The rocks may appear structureless or have indistinct wavy laminations and bands. Unit 8, measured section 3, is faintly rippled on some exposures. Frequently the valves are absent at the base of the beds and increase in abundance toward the top. The beds may be separated by mudstone layers that grade upward into the limestone. Mud and silt occur in the matrix. Based on these characteristics it is interpreted that these ostracod fossils have sometimes been worked by relatively low energy currents but not transported over great distances. They probably originated along the lake margin within the stagnant marshland, pond, or lagoon where they were finally deposited. The upward succession of thin mudstone layer to lime mudstone to ostracod lime packstone of some beds may indicate the initial influx of fine sediment as a wet period began, followed by increasing numbers of ostracods as dormant eggs hatched and successive broods appeared, or as species succeeded each other.

Lake level changes, either annual or longer period, may have been related to this apparently cyclic behavior. Dessication features are not typical of these deposits and a rigorous flooding-drying cycle should not be assumed. Oxygen and nutrients carried in by increased flow of tributary streams would invigorate the lake as a whole, and flood basin runoff along with the rising lake level would carry this effect into the marginal environments. If the dry season had increased chemical concentrations in the water through evaporation, these would be diluted, especially around the margins. Coupled with seasonal patterns, a new cycle of growth could have been triggered in what had become a dormant, stagnant environment. The absence of fossils of other organisms indicates a difficult environment in which the ostracods not only survived, but thrived.

Conditions similar to those just described have been observed in shallow bays along the east side of the Great Salt Lake. Dilution of brackish or saline waters by increased freshwater inflow allows freshwater algae and other freshwater microorganisms to utilize the nutrients in both the sediments and inflowing water, producing algal blooms (Elmer in press).

The limestone at the top of measured section 12 is not an ostracod packstone, but overlying ostracod-rich shales, which also contain fragments of gastropods, indicate a neighboring environment with higher energy and clastic influx where ostracods were also abundant.

Above the ostracod-rich strata is a sequence of calcareous shales and shaly limestones that are interpreted to have been deposited in higher-energy, more open water portions of the lake margin with increased water depth.

The uppermost well-exposed rock type of the Colton–Green River transition zone is the *Goniobasis* lime packstone. Because snails are epifaunal, relatively low energy would have been required to concentrate these snail shells. The dominantly unbroken shells, some with details of ornamentation well preserved, indicate low energy levels were involved in assembling the original coquinas.

Kukal (1971) indicated that, at least in certain lakes, development of shell concentrations is characteristic. Shells are concentrated into three zones:

1. An upper zone where surf ejects empty shells onto the shore line.
2. A middle zone developed where shoreward-moving wave energy and offshore-returning bottom currents interfere. This zone is usually less pronounced.
3. The deepest zone, where shell concentration is greatest, at the littoral-profundal boundary. This zone forms where back-current weakens. In flat, shallow lakes this lies at about 2 m.

Back currents could result from bottom return of surf (Kukal 1971), but equilibrium countercurrents resulting from wind tides and seiches could provide strong and frequent components.

Gill-breathing *Goniobasis* preferred turbid, aerated water but also lived in clear water (La Rocque 1960). Baer (1969) found *Goniobasis* indicated clearer water conditions than did *Viviparus*. He considered *Goniobasis* packstone an indicator of the more lakeward portion of the shoreline environment where waves had winnowed and abraded the shells.

Goniobasis packstone in Emma Park indicates a similar interpretation. Well-preserved shells indicate they were not subject to high-energy storm waves piling them onto the beach, but rather were deposited below the lake waters in lower energy regimes such as the third shell zone described by Kukal (1971) or the transitional-sublittoral zone of Reineck and Singh (1975, p. 323–26, fig. 478).

The *Goniobasis* and ostracod lime packstones are distinctive features of the Colton (Wasatch)–Green River transition zone and were noted by Bradley at both Willow Creek (1931) and in the Green River basin of Wyoming (1964). Picard (1955) and Swain (1956) correlated them with the lowermost Green River Formation, and Roberts (1964) used electric logs and well cuttings to identify this basal Green River zone. These two packstone units persist over most of Emma Park. Ostracod lime packstone appears in higher exposures of Colton–Green River intertonguing, but *Goniobasis* lime packstones are absent. This is consistent with observations of Bradley (1931) and Moussa (1969) in this same general area. The reason for disappearance of *Goniobasis* packstones in higher deposits is unknown.

Exposures above the ostracod-*Goniobasis* lime packstone sequence are too poor for detailed analysis of succeeding environments, but three general environments can be distinguished on measured sections 3 and 6.

The first zone is approximately 80 to 100 m thick and is mostly covered by slope. It corresponds to the Basal Tongue of the Green River Formation of Bradley (1931) or Middle Fork Tongue of the Green River Formation of Moussa (1969). This tongue includes the transition beds already described. Patchy exposures and rubble indicate that yellowish gray-weathering shales, shaly siltstones, and light bluish gray-weathering paper shales underlie the covered slope. These sediments are interpreted as deposits from deeper lake water that transgressed into the area. The papery splitting shales that weather light bluish gray are oil shales (Cashion 1957) representing nonoxidizing bottom conditions and sedimentation incorporating detritus from seasonal algal growth (Bradley 1929). Unit 11 and unit 9, measured section 6, are silty limestones representing shallow ponds or lagoons left as the lake withdrew from the area and subaerial environments returned.

Units 9 to 22, measured section 6, were deposited as subaerial deltaic environments returned to the area. This is the Tongue of Wasatch Formation of Bradley (1931) or Tabbyune Creek Tongue of the Colton Formation of Moussa (1969). This deltaic tongue is roughly 50 m thick here and is dominated by red mudstone. Unit 15, measured section 6, is a gray green mudstone deposited in a poorly drained portion of the delta. Thick, lenticular ledge-forming sandstones are exposed in this sequence above measured section 7 (fig. 3). Unit 13, measured section 6, indicates a unimodel sediment transport direction of 340° and is cross-bedded. Unit 13 and unit 18 may represent thin channel deposits, but there are no definitive diagnostic structures visible.

The third zone covered by measured section 3 and 6 marks a return to transitional deposition and grades upward to open lacustrine deposition. Sandstones are thin to medium bedded. Some, such as units 26 and 24, measured section 6, contain indistinct cross-lamination, but most are massive. Sandstones generally are most common at the bottom of the section, but two thick channel sandstones, unit 45, measured section 6, and unit 1, measured section 13, lie fairly high in the section. Units 40 and 42 of measured section 6 are paper shales closely associated with ostracod lime packstone, showing that the thin varves often associated with deep-water deposition could be formed in or near the shallow marginal waters where ostracods were deposited. Unit 20 of measured section 11 indicates a similar relationship in the Colton–Green River transition zone. This third zone is topped by a prominent ledge of shale and corresponds to Moussa's (1969) Soldier Summit Member of the Green River Formation. Bradley (1931) placed this ledge in the middle of his "second lacustrine tongue of Green River formation" and identified it as a low-grade oil shale. No distinctive *Goniobasis* lime packstones were observed in this member.

Using mainly the ostracod-rich limestones present in these units, Roberts (1964) traced these basal Green River Formation units, which he called the Willow Creek Interval, in the subsurface over a large part of the Uinta Basin. He interpreted fluctuations of lake level as the source of these major intertonguings (p. 71). He related the level changes to climate changes.

COLTON–GREEN RIVER CONTACT

Spieker (1946, p. 139) described the color contrast of the red Colton floodplain and channel deposits against the gray to white of the overlying and underlying lacustrine deposits as a "convenient criterion for recognition and mapping" and also as a valid distinction between the two sediment types. He also contrasted the lenticular, irregular nature of the Colton Formation against the regular bedding of the lacustrine Flagstaff and Green River deposits. Spieker considered the contacts at Colton clearly defined, based on these characteristics, but he realized them to be stratigraphic limits of local value only. He recognized intertonguing of the formations throughout the region and westward gradation of Colton into Green River-type beds.

From a distance the color change between the Colton and Green River Formations in Emma Park is the most easily recognized feature of the contact. The exact location of this color change may not be as obvious when standing right at the outcrop, which is typically a steep, weathered, and covered slope. The color change may be evident on adjacent exposures and can be easily projected from these. Shallow digging can often uncover the color change, and deep erosion occasionally exposes it. This color transition zone consists of interfingering red-hued and gray to green-hued mudstones. There are also thin limestone, sandstone, and siltstone strata. Red-colored mudstones dominate the color of the weathered slope and the color change of the slope seems to correspond closely with the topmost occurrence of red mudstone.

Measured section 12 illustrates how interfingering of gray and red-hued rocks becomes more extensive westward from Emma Park (fig. 30). Gray and yellowish gray colors dominate from unit 38 up. Below lie 40.2 m of red mudstone in units 35, 36, and 37. Red and gray mudstone intermingle on the weathered slopes of units 34 and 32. Lower in the section, thick gray mudstones of units 24, 22, and 20 and 19 are separated by thinner red mudstones of units 23 and 21. Interfingering of these colors is clear on this measured section, but at a poorly or partially exposed outcrop or from well cuttings; confusion or incorrect identification of the contact could result if color were the only criterion. Picard (1955) arbitrarily placed the base of the Green River Formation at the first occurrence of red shale.

Moussa (1965) mapped the Green River–Colton contact in the Soldier Summit Quadrangle where contact between the two formations is gradational. He related his contact to the color change in places, but considered the base of the lowermost paper shale as the most valid criterion for establishing the Colton–Green River stratigraphic boundary. It was the lack of paper shales that permitted Moussa to extend the Colton westward beyond the last red colored deposits. Bradley (1931, plate 11) placed the base of the Green River Formation at the base of the lowermost paper shale at Willow Creek (Indian Canyon Section).

Exposures of paper shale are uncommon in the sections measured in Emma Park, and using paper shales to define the contact would have been futile. Paper shales in units 24, 25, and 27 of measured section 7, unit 13 of measured section 3, and unit 10 of measured section 2 lie immediately below ostracod lime packstone that forms a projecting ledge and prevents the shales from being covered by slope debris. Exposures are not generally extensive laterally or vertically. Paper shales, well exposed as unit 44 of measured section 12, overlie limestone that is laterally equivalent to the ostracod lime packstone.

Roberts (1964) used high resistivity and high spontaneous potential values of the ostracod, gastropod, and pelecypod lime packstones (Roberts' near-coquina) in well logs to define the Colton–Green River contact in the subsurface where the Colton (Wasatch) was mainly mudstone. In areas where both Green River and Colton (Wasatch) were sandy, electric log response alone was not reliable and Roberts used well samples to place the contact at the lowermost ostracod limestone. In certain instances Roberts used simply the lowermost occurrence of ostracods. Measured section 12 might illustrate, in outcrop, an example of this last possibility. Ostracod lime packstone is absent in this section and ostracods are not evident in the other limestones, units 39, 41, and 43. Sandstone is abundant in units 38 and 40. The lowest evident occurrence of ostracods is in the paper shale, unit 44. Well cuttings from a well drilled through a similar sequence of rocks would also show the color change between units 37 and 38, below the last ostracod occurrence.

For the present study color was a primary criterion for identifying the Colton and Green River formations, and the contact was placed at the color change. Where the contact was covered, the location was estimated by projecting it from adjacent slopes with exposures and by estimating thickness downward from the ostracod lime packstone ledge (fig. 25). Ostracod lime packstone forms a prominent and extensive ledge in Emma Park and provided a useful datum for measuring sections. The identical limestone was not present at Kyune, but a prominent limestone ledge lacking in ostracods, overlain by ostracod-rich paper shales, was identified as the lateral equivalent based on observations from the valley floor. Change in vertical separation between the ostracod lime packstone and color change is seen in fig. 30. These two features occur closer together in Emma Park than in the West Fork of Willow Creek. Occurrence of thinly laminated, papery splitting shales is the least useful criterion for marking the Colton–Green River contact in Emma Park as exposures of the paper shale are neither extensive nor numerous.

Red-colored rocks underlying the Green River Formation have traditionally been called "Wasatch Formation" in the subsurface of the Uinta Basin. Fouch (1975) has shown that Flagstaff Limestone, or the Flagstaff Member of the Green River Formation as he calls it, extends beneath most of the Uinta Basin, that the divisions of the Wasatch Formation made by Spieker (1946) apply throughout most of the basin, and that what has been called the Wasatch Formation may, in many cases, be correctly identified as the Colton Formation.

DEPOSITIONAL MODEL AND PROJECTION INTO THE SUBSURFACE

A lateral succession of depositional environments is exposed along the strike valley formed by the Colton Formation (fig. 28). Zawiskie and others (1982) described a sandstone-dominated fluvial plain sequence in the Colton Formation exposed in the vicinity of Sunnyside, overlain and underlain by a mudstone-dominated sequence of rocks similar to those in Emma Park. This sequence of facies persists westward to Pole Canyon (Anderson 1978) and Soldier Creek (Zawiskie and others 1982). The dominantly mudstone Colton at Emma Park was deposited on the deltaic plain, with a part of the uppermost exposures indicating fluvial plain-type environment was beginning to intrude before Colton deposition ceased locally. The Colton exposures at Kyune show rocks deposited lower on the deltaic plain close to local base level, resulting in poorly drained, reducing environments. Gray and red mudstone deposition alternated for periods, but red oxidized floodbasin mudstone containing lenticular meandering channel sandstones still dominated. Between Kyune and Colton, Peterson (1976) identified an upward succession of prodelta, delta front, straight channel distributary, and delta-plain meandering channel–flood-basin deposits in the lower Colton. Westward from Colton to the Soldier Summit area Moussa (1965) found red beds greatly reduced in total thickness and concentrated in the lowermost sediments,above the Flagstaff Limestone. Channel and floodplain deposition in the upper Colton had been replaced by Green River Formation-type deposits, especially limestone. At Thistle, to the west, Colton is missing entirely and Green River Formation lies conformably on Flagstaff Limestone (Spieker 1946; Ryder and others 1976).

Both small-scale interfingering and large-scale intertonguing of lacustrine and delta plain deposits extend at least from Soldier Summit (Moussa 1965) to Sunnyside (Hendel 1957).

The depositional history of the Colton Formation interpreted from exposures in Emma Park and other locations along the Colton strike valley is:

1. Westward displacement of Lake Flagstaff and rapid progradation of the subaerial deltaic-fluvial system into the basin as far west as the Soldier Summit area.
2. Establishment of near equilibrium between lacustrine and deltaic depositional environments, with the shoreline lying between Kyune and Soldier Summit. Equilibrium also existed between downward tectonic movement of the basin and upward filling of the basin by sediment. Emma Park was the locale of delta plain deposition, with meandering, bifurcating streams.
3. Avulsion of the principle delta-building stream and outward expansion of the lake introduced transitional shoreline, then open lacustrine depositional environments through the Emma Park area.
4. A new period of equilibrium was reached with the shoreline along the Sunnyside–Peters Point alignment.
5. Deltaic plain depositional environments reoccupied the Emma Park area as the stream built another lobe of subaerial delta into the lake.
6. Lacustrine conditions expanded across the area again and the thick main sequence of Green River Formation rocks was deposited.

Sediment transport directions of Peterson (1976) indicate stream flow ranged generally northwest to northeast. Measurements in Emma Park for this study show a broad distribution, but the mean direction is to the northwest (fig. 2). Measurements of sediment transport direction in the Colton by Stanley and Collinson (1979) and Zawiskie and others (1982) agree with northwest to northeast transport.

Projection of the strike of the depositional model northeast from Emma Park places the lacustrine-deltaic transition as it is shown on fig. 29. Using the Catatumbo delta as a model gives a broadly arcuate shape to the projection, rather than a straight front. Fouch (1975) and Ryder and others (1976) have shown the locations of the open lacustrine, marginal, and fluvial facies in the subsurface.

OIL AND GAS POSSIBILITIES

The Colton Formation and Green River Formation exposed in Emma Park dip northward and occur in the subsurface across much of the Uinta Basin (Fouch 1975). Commercially productive volumes of oil and gas have been found in sandstone reservoirs in these rocks. The IAPG Guidebook to the Geology of the Uinta Basin (Seal 1975) contains papers on several of the earlier fields. Summaries of Uinta Basin fields were given by Picard (1956), Folsom (1963), and Porter (1963). Lucas and Drexler (1975) discussed Altamont-Bluebell. Production data were contained in statewide summaries for Utah by Preston (1961) and Brown and Ritzma (1981). Hydrocarbons have also been produced from similar rocks in the Piceance Creek Basin in Colorado (Chancellor and others 1974).

The trapping mechanism is usually a porosity and permeability barrier of mudstone or shale surrounding a porous lenticular sandstone (Folsom 1963). Faulting, as at Duchesne Unit (Picard 1955), may produce the trapping mechanism. Fracturing, as at Altamont-Bluebell (Lucas and Drexler 1975), may enhance reservoir porosities. Structural closure is found at Brennan Bottoms (Picard 1955) and Jack's Canyon (Hendel 1957), but structure generally functions to enhance stratigraphic accumulation, rather than to act as the primary trapping mechanism in these Tertiary reservoirs. Oolitic ostracodal grainstones have produced at Bluebell, Brennan Bottoms, and Red Wash fields (Fouch 1975).

Hydrocarbon production nearest to the study area is at Stone Cabin, located in T. 12 S, R. 14 E (SLM), Carbon and Duchesne Counties (fig. 28). A small amount of gas was produced from the Colton Formation before abandonment of the field in 1960 (Brown and Ritzma 1981). The Wasatch Formation produces oil and gas at Duchesne Unit, approximately 50 km to the northeast of Emma Park, in T. 4 S, R. 4 W (USM), Duchesne County (Brown and Ritzma 1981). Production is from the top of the

Colton Formation (Picard 1955), which probably accumulated in depositional environments similar to upper Colton–basal Green River formations at Emma Park. Other Colton production near to Emma Park is in Carbon County, Utah, at Jacks Canyon and Peters Point Units, in T. 12 and 13 S, R. 15–17 E (SLM). These fields are approximately 60 km east of Emma Park and 30 km northeast of Sunnyside, Utah (fig. 28). Hydrocarbon reservoirs at Peters Point Unit have been interpreted as NE–SW-oriented elliptical sandstone lenses that were formed in nearshore environments during the first expansion of Lake Uinta across the Colton deltaic plain (Hendel 1957). Tar sands in the basal tongue of the Green River Formation (Murany 1964) crop out along the Book Cliffs near Sunnyside, Utah. They are aligned roughly NE–SW with Peters Point Unit and, based on intertonguing of red beds, sandstone lenses, and ostracodal-oolitic limestones, they also have been interpreted as nearshore deposits (Hendel 1957, p. 198). Hendel (1957, p. 198) described the tar sands as the same sequence of sandstones that serve as oil and gas reservoirs at Peters Point. Asphaltic residues are found in sandstone beds above the producing horizons at Peters Point (Hendel 1957, p. 198). Gas has also been produced at one well from a fluvial sandstone in the middle of the Colton Formation at Peters Point Unit (Hendel 1957).

Murany (1964, fig. 4) indicated that oil or gas exploration for Colton reservoirs west of Peters Point–Jacks Canyon would not be economical due to increasing depth, low sand/shale ratios, and small reservoir size. On the other hand the transitional lacustrine-deltaic rocks that trap hydrocarbons in the Uinta Basin are exposed in the Soldier Summit area and can be projected to the northeast (fig. 28). Open-lacustrine facies source-rocks lie downdip of the potential reservoirs (Fouch 1975) and deltaic-fluvial mudstones provide an updip seal. In addition to a band of stratigraphic trap potential, the structures such as Clear Creek Anticline would provide structural enhancement possibilities.

Altamont-Bluebell field production is associated with a wedge of Colton sediments that thin southward into the basin. The Uinta uplift is the source of these clastic sediments (Lucas and Drexler 1975). Oil is produced from lake margin deposits both above and below the Colton sediments (Lucas and Drexler 1975). In the present study lake margin deposits were found at the base of the Colton Formation only at the eastern edge of the area studied along Willow Creek (measured section 10). Across the rest of the area, red beds were found directly on lacustrine limestone. Spieker (1946) described the same sharp contact at Colton, and Moussa (1965) found it present to the western limits of red bed deposits. Indications then are poor for hydrocarbon traps beneath the Colton in the southwestern Uinta Basin, but the sharp contact that has been exposed may not be extensive along strike into the subsurface. Lake margin deposits exposed along Willow Creek indicate that there is some possibility of reservoir development at the base of the Colton sediments. A program of hydrocarbon exploration in the Colton deposits of the southwestern Uinta basin should consider evaluation of this possibility.

APPENDIX: MEASURED SECTION 5

Measured section 5 starts at a sandstone outcrop next to the county road, on the north side, approximately 300 m east of Matts Summit.

Flagstaff Limestone, Colton Formation, and base of Green River Formation.

Unit	*Description*	*Unit Thickness (meters)*	*Cumulative Thickness (meters)*
Middle Fork Tongue of Green River Formation (lower part only)			
63	Limestone: packstone of gastropod and bivalve shells and shell fragments; laminated; poor exposure, ledgy slope former.	0.5	431.1
62	Covered slope: probably shale that weathers light brown to yellowish gray.	13.5	430.6
61	Limestone: ostracod lime packstone; weathers yellowish gray; splits into flaggy angular rubble; fresh surface banded, light olive gray with dark material filling ostracod shell, moldic porosity and yellowish gray with clay partially filling the pores; strong petroliferous odor on a fresh break; poor exposure, ledgy slope, but well exposed to the east.	0.4	417.1
60	Covered slope: a few exposures of yellowish gray-weathering mudstone; exposed slope to the east shows light brown-weathering mudstone or shale.	9.0 (est.)	416.7
Colton Formation			
59	Covered slope: exposed slope to east shows red-weathering mudstone. 59 and 60 measure 18 m together.	9.0 (est.)	407.7
58	Interbedded sandstone and mudstone: weathers yellowish gray, fresh surface light gray. The sandstone is fine grained, silty, calcareous, and porous; 80% quartz, equant, rounded; 10% chert, equant, subangular; 10% black	6.0	398.7

	minerals, equant, angular. Fair exposure, ledgy slope former.		
57	Covered slope: patches of red and greenish gray show through in places; slope to the east dominantly moderate red-weathering mudstone.	8.5	392.7
56	Mudstone: weathers moderate red; patches of greenish gray color; poor exposure, slope former.	15.0	384.2
55	Mudstone: weathers light gray; poor exposure, slope former.	0.5	369.2
54	Mudstone: weathers moderate red; poor exposure, slope former.	0.1	368.7
53	Mudstone: weathers greenish gray; poor exposure, slope former.	0.3	368.6
52	Mudstone: similar to unit 54.	17.5	368.3
51	Mudstone: similar to unit 55.	1.0	350.8
50	Mudstone: similar to unit 54.	6.0	349.8
49	Mudstone: similar to unit 53.	0.5	343.8
48	Mudstone: similar to unit 54.	43.5	343.3

Offset in section

47	Sandstone: calcareous, porous, silty; weathers very pale orange, fresh surface is light olive gray; fine-grained 95% quartz, equant, rounded; 5% black minerals, equant, subangular; thin sets of trough cross-beds; sediment transport direction 350° to 30°. Molds of small bivalve shells are rare. There are dark gray patches up to 2 cm diameter, probably rip-up clasts of organic rich mud. Fair exposure, ledge former.	3.9	299.8
46	Covered slope: slope of red-weathering mudstone exposed to the east.	18.3	295.9
45	Sandstone: calcareous, silty, fine grained; weathers yellowish gray, fresh surface is greenish gray; composition similar to unit 58; parallel beds; main channel sandstone body is about 25 m to the west; sediment transport direction approximately 340°; fair exposure, ledgy slope former.	0.9	277.5
44	Mudstone: similar to unit 54.	4.5	276.7
43	Sandstone: silty, calcareous; similar to unit 45 except: it is a deposit of a westward-migrating point bar; trough cross-bedded; sediment transport direction 350° to 360°; hematite nodules along some bedding surfaces, possibly formed around organic material; good exposure, ledge former, thins about 100 m to the east.	7.0	272.2
42	Covered slope: patches of moderate red-weathering siltstone exposed, probably red mudstone with siltstone beds.	30.0	265.2
41	Mudstone: similar to unit 54.	1.0	235.2
40	Sandstone: fine grained, poorly cemented; weathers pale red, light gray on a fresh surface; poor exposure, ledgy slope former exposed in gullies.	0.3	234.2
39	Mudstone: similar to unit 54.	11.5	233.9
38	Sandstone: fine grained, silty, porous, well sorted, calcareous; weathers pale red; fresh surface medium gray, mottled with pockets of darker gray silt approximately 1 mm in diameter; weathered surface is pocked where the silt has been eroded; very thin bedded. The grains are 60% quartz, equant, subrounded; 30% chert, equant, subangular; 10% black minerals, equant, subangular. Fair exposure, ledgy slope former.	0.6	222.4
37	Mudstone: similar to unit 54.	2.2	221.8
36	Sandstone: weathers moderate brown, light greenish gray on a fresh surface, weathered surface is pocked; thin bedded; levee deposit, fair exposure, ledgy slope former.	0.4	219.6
35	Mudstone: similar to unit 54.	14.5	219.2

Offset in section

34	Sandstone: silty, weathers yellowish gray, fresh surface is light brown; composition similar to unit 38, except chert stained by limonite; trough cross-bedded; sediment transport direction 0° to 20°; good exposure, ledge former that thickens to the west, about 10 to 12 m thick 100 m to the west.	2.8	204.7
33	Mudstone: similar to unit 54.	1.2	201.9
32	Mudstone: weathers greenish gray; poor exposure, slope former. May represent major transgression of lake onto the delta.	12.0	200.7
31	Mudstone: similar to unit 54.	6.5	188.7
30	Limestone: weathers greenish gray; silty; bivalve fragments common.	0.1	182.2
29	Mudstone: weathers greenish gray, dark greenish gray on fresh surface.	0.7	182.1
28	Mudstone: similar to unit 54.	5.0	181.4

Offset in section

27	Sandstone: Three separate lenticular composite sets of a westward-migrating point bar. The lowest body weathers light greenish gray, the middle body has areas of both pale red and light greenish gray weathering, and the highest	11.5	176.4

	body weathers pale red; greenish gray color probably secondary, caused by migration of reducing fluids through the sandstone. Sandstone is fine grained; composition similar to the sandstone in unit 58. The unit is flat topped, top surface has abundant root marks. There is a laminated mudstone bed between the top composite set and the lower two; the composite sets made of thin sets of trough cross-beds; sediment transport direction approximately 340°; good exposure, prominent ledge former.		
26	Covered slope: pale red-weathering mudstone exposed to the east.	20.0	164.9
25	Mudstone: similar to unit 54.	9.0	144.9
24	Sandstone: very porous, calcareous, fine grained; weathers pale yellowish brown; fresh surface is mottled and may vary from yellowish gray to greenish gray; planar, parallel sets of cross-laminated sandstone separated by mudstone laminations; direction of sediment transport approximately 315° to 330°; root marks abundant on top of and throughout the sandstone; levee deposit; fair exposure, ledgy slope former. Other similar outcrops can be found to the east, and the main channel deposit is 400 m to the east.	8.0	135.9
23	Covered slope: red-weathering, slope forming mudstone exposed 100 m to east.	10.5	127.9
22	Sandstone: laminated; poor exposure, levee deposit associated with point bar 100 m to west.	4.0	117.4
21	Mudstone: poor exposure, weathers to a red, gray, and green variegated slope.	3.0	113.4
20	Covered slope: upper half shows red coloration, red mudstone exposed 100 m to the east.	13.5	110.4
19	Siltstone: cross-laminated, ripple marked; weathers moderate red to dusky red, fresh surface is light gray; fair exposure, caps a low ridge.	0.5	96.9
18	Mudstone: similar to unit 21.	22.5	96.4
17	Interbedded very thin-bedded sandstone and shale; sandstone beds are planar and parallel, some subtle trough cross-beds; weathered and fresh surfaces light gray; sediment transport direction is generally northward; poor exposure, ledgy slope former with flaggy splitting.	6.5	73.9
16	Mudstone: similar to unit 54. Gypsiferous seep about halfway up the slope.	4.2	67.4
15	Sandstone: silty, well cemented, salt-and-pepper appearance; weathered and fresh surfaces light gray; laminated to thin bedded, rooting action has destroyed much of the sedimentary structure; sediment transport direction approximately 355°; grain composition approximately 10% black minerals, 40% chert and rock fragments, and 50% quartz; grains are fine, equant, and subrounded; poor exposure, ledgy slope former; levee deposit.	3.6	63.2
14	Mudstone: similar to unit 54.	1.5	59.6
13	Sandstone: salt-and-pepper appearance; weathered and fresh surfaces light gray; parallel laminations; direction of sediment transport is 335° to 360°; poor exposure, ledgy slope former; levee deposit.	3.1	58.1
12	Mudstone: transitional body at the base of the overlying sandstone; weathers greenish gray; poor exposure, slope former.	2.0	55.0
11	Mudstone: similar to unit 54.	8.3	53.0
10	Sandstone: laminated to thin trough cross-bedded, possibly the slip-off face of a point bar; sediment transport direction approximately 350°; rip-up clasts of red mudstone and parting lineations. Several similar, lenticular composite sets offset and stacked to west. Poor exposure, ledgy slope former; exposed longitudinally across slope to the west.	1.9	44.7
9	Mudstone: similar to unit 54. Channel sandstone body just west of the section, at about 4 m, approximately 5 m across and 1 m thick.	10.7	42.8

Offset in section

8	Sandstone: weathers pale red; very thin, horizontal, parallel bedding; beds contain rip-up clasts and burrows; fair exposure, ledgy slope former; levee deposit to point-bar deposits to the west with sediment transport direction approximately 15°.	0.5	32.1
7	Sandstone: laminated; rooting has destroyed much sedimentary structure; sediment transport direction approximately 335°; levee deposit, grades into point-bar deposit to the east; fair exposure, ledgy slope former.	3.0	31.6

6	Sandstone: thin, trough cross-beds with mudstone clasts along the bedding surfaces; two composite sets with mudstone between; composition similar to unit 47; sediment transport direction 325° to 360°; fair exposure, ledgy slope former; levee deposit to point-bar deposit to the west.	5.5	28.6
5	Mudstone: similar to unit 54.	14.0	23.1

Flagstaff Limestone

4	Limestone: algal-ball lime wackestone; algal balls formed around whole *Viviparus* gastropod shells; abundant algal debris in the matrix, shells filled with lime mud matrix; weathers pale red; matrix light gray, algae medium dark gray on a fresh surface. The algal balls weather out and litter the surface; they are up to 5 cm in diameter. Good exposure, ledge former, easily followed across the surface laterally.	0.6	9.1
3	Mudstone: weathers greenish gray; poor exposure, slope former.	2.0	8.5

Tongue of Colton Formation (upper part only)

2	Mudstone: weathers moderate red; poor exposure; slope former.	2.5	6.5
1	Sandstone: trough cross-bedded point-bar deposit; direction of sediment transport approximately 335°.	4.0	4.0

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