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SEDIMENTOLOGY OF THE MESAVERDE FORMATION AT RIFLE GAP, COLORADO AND IMPLICATIONS FOR GAS-BEARING INTERVALS IN THE SUBSURFACE

by

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ABSTRACT

The exposures of the Mesaverde Formation at Rifle Gap, Colorado, are of a regressive series of marine to fluvial deposits about 1650 m (5000 ft) thick. Grading up out of the marine Mancos Shale, the blanket shoreline sandstones of the Corcoran, Cozzette, and Rollins Sandstones record substages of the regression as delta lobes were activated and abandoned in northwestern Colorado during Late Cretaceous time. The overlying coals, sandstones, and carbonaceous mudstones were deposited on the paludal lower delta plain behind the shoreline. Meandering fluvial systems prograded over the paludal deposits. These systems deposited point-bar sandstones and overbank mudstones and siltstones in composite meander-belt trends, some of which are now gas-bearing, low-permeability reservoirs. Reorientation of the paleogeography during the Laramide orogeny (contemporaneous with fluvial deposition) probably changed the orientation of the meander belt trends. The uppermost sandstones at Rifle Gap, including the Ohio Creek conglomerate, are interpreted as shoreline deposits of a transgression that has been previously unrecognized in the area. Most of the record of this transgression has been destroyed by pre-Eocene erosion.

The outcrops at Rifle Gap provide a basis for interpreting subsurface deposits in the Department of Energy's Western Gas Sands Project Multi-Well Experiment, 12 miles away.

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SEDIMENTOLOGY OF THE MESAVERDE FORMATION AT RIFLE GAP, COLORADO AND IMPLICATIONS FOR GAS-BEARING INTERVALS IN THE SUBSURFACE

Introduction

The Mesaverde Formation in the Piceance Creek basin is a unit of nonmarine sandstones, mudstones, and coals, estimated to contain some 40 trillion cubic feet of gas in low-permeability, lenticular reservoirs. The Department of Energy's Western Gas Sands Project Multi-Well Experiment (MWX, Atkinson et al, 1981) is involved in developing and improving technologies for producing the gas from this type of reservoir in the Piceance Creek basin. This study of the sedimentology of the Mesaverde Formation is part of the MWX. It is primarily a study of Mesaverde outcrops as near as possible to the MWX site, so that interpretations at the surface may be extrapolated into the subsurface at the MWX site and used to characterize the sandstone reservoirs.

Mesaverde outcrops were studied and measured at and near Rifle Gap during the summer of 1981, and the preliminary sedimentologic interpretation (prior to study of MWX cores) are set out in this report. A geologic road log of Rifle Gap has been incorporated into the text in order to facilitate visualization of the types of rocks drilled through and tested in the MWX.

Paleogeographic Setting

During most of Cretaceous time, from about 135 to 65 million years ago, much of North America between the Rocky Mountains and the Mississippi River was a shallow interior seaway. Little is known about the eastern shore of this seaway, but on its western edge active mountain building took place in the Rocky Mountain area. The abundant sediments eroded from these mountains, and also derived from contemporaneous volcanic activity, were transported east to form a coastal plain on the edge of the seaway (Fig. 1). Subsidence of the earth's surface below the coastal plain accommodated the deposition of up to 7300 m (23,000 ft) of sediments (Reeside, 1944) along the Rocky Mountain front in the United States. The width of the coastal plain and the position of the western shoreline of the seaway varied according to the position and rate of influx of sediments from the mountains, and according to the variation of eustatic sea level (Hancock and Kauffman, 1979). These controls produced relative transgressions and regressions of the seaway.

During most of Late Cretaceous time, northwestern Colorado was part of the interior seaway. The marine Mancos Shale was deposited in this seaway. About 76 million years ago, the next to last regression of the seaway began. As the shoreline prograded erratically to the southeast across northwestern Colorado, it left behind the shallow-marine to shoreface blanket deposits presently known as the Castlegate, Sego, Corcoran, Cozzette, and Rollins (also called the Trout Creek) Sandstones.

Behind these sandstones, the coals, mudstones, and sandstones of the paludal (lower) part of the Mesaverde Formation were deposited in swamp, lacustrine, and fluvial distributary channels. The erratic regression is recorded by the repetitive/cyclic nature of the shoreline and lower paludal deposits, which are interbedded with tongues of marine Mancos Shale deposited during temporary returns of the seaway.

With continued progradation of the coastal plain, the sites of paludal deposition moved eastward, and the marine deposits in northwestern Colorado were buried by the deposits of the succeeding fluvial environment. Fluvial

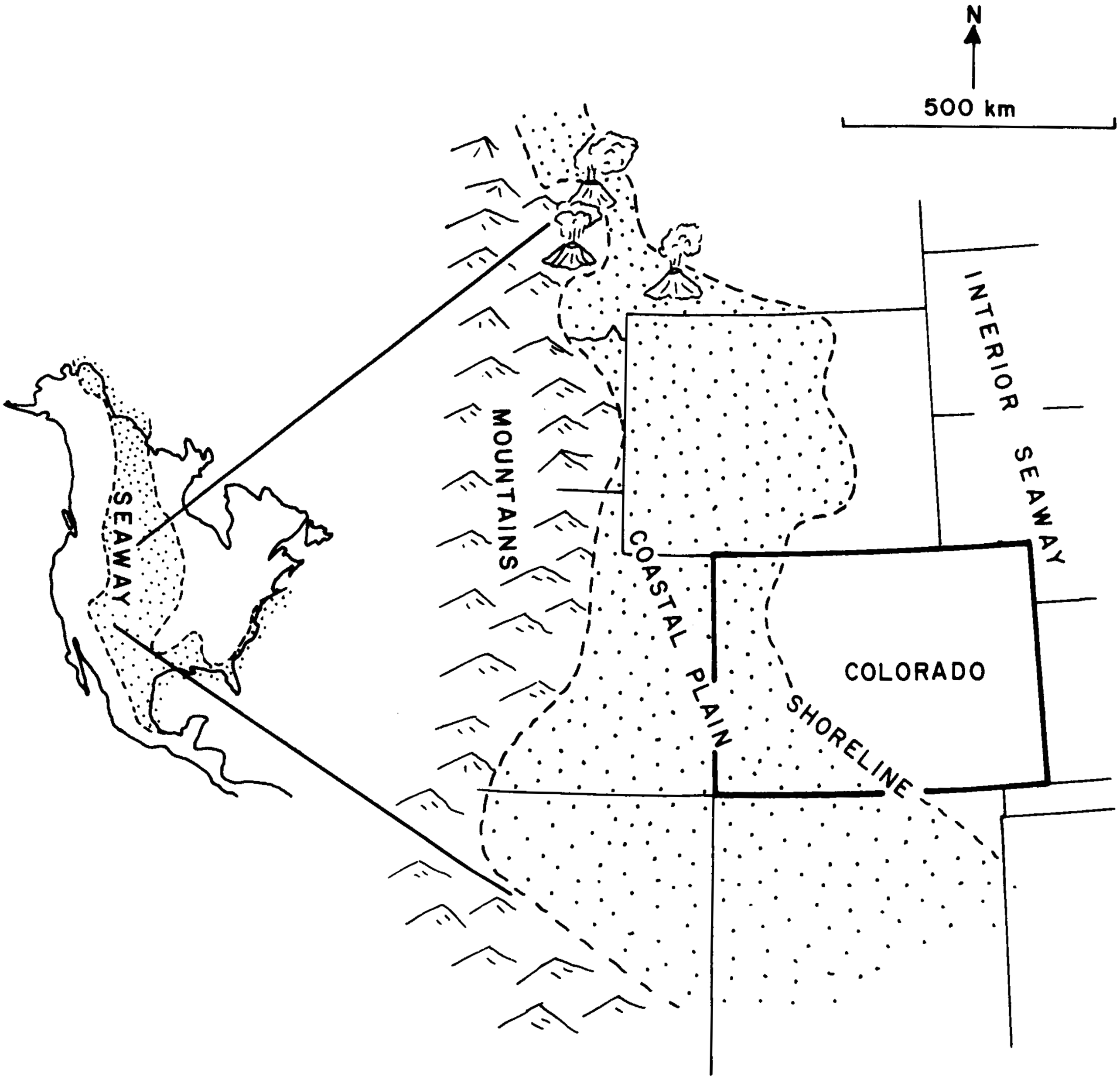

Figure 1. Generalized paleogeography of the central Rocky Mountain region during Late Cretaceous time (after Mallory et al, 1972).

sandstones and mudstones accumulated on the coastal plain of the upper Mesaverde Formation of northwestern Colorado, until the last transgressive episode of the Cretaceous, approximately 72 million years ago. At this time, shoreline sandstones and marine shales (the Lewis Shale) were again deposited in the area, only to be replaced in turn by the coastal plain deposits of the final Cretaceous regression.

During deposition of the Mesaverde Formation, the initial phases of the Laramide orogeny were under way. This tectonic event readjusted the positions of various blocks of the earth's crust in western North America, causing both uplift and subsidence. It was responsible for the eventual structural isolation of the Piceance Creek basin, and probably the eastward thickening of the Mesaverde Formation. During deposition of the upper parts of the Mesaverde Formation in the Piceance Creek basin, the Sawatch Mountains, and probably the Uncompahgre uplift (Fig. 2) were elevated (Tweto, 1980).

These uplifts caused local reorientations of Mesaverde drainage, and created new sources of sediment. They also caused local erosion of previously deposited sediments. In the eastern Piceance Creek basin, sediments which form the Ohio Creek Conglomerate (the top member of the Mesaverde Formation, Johnson and May, 1980), and the overlying Wasatch Formation, were derived from these uplifts. The uplifts also caused the erosional surface overlying the Ohio Creek Conglomerate, where the Lewis Shale may once have existed. The eventual uplift of the White River plateau tilted the rocks along the Grand Hogback. This and minor arching to the north and west of the basin resulted in the enclosed basin of internal drainage in which the lacustrine "oil shales" of the Green River Formation were

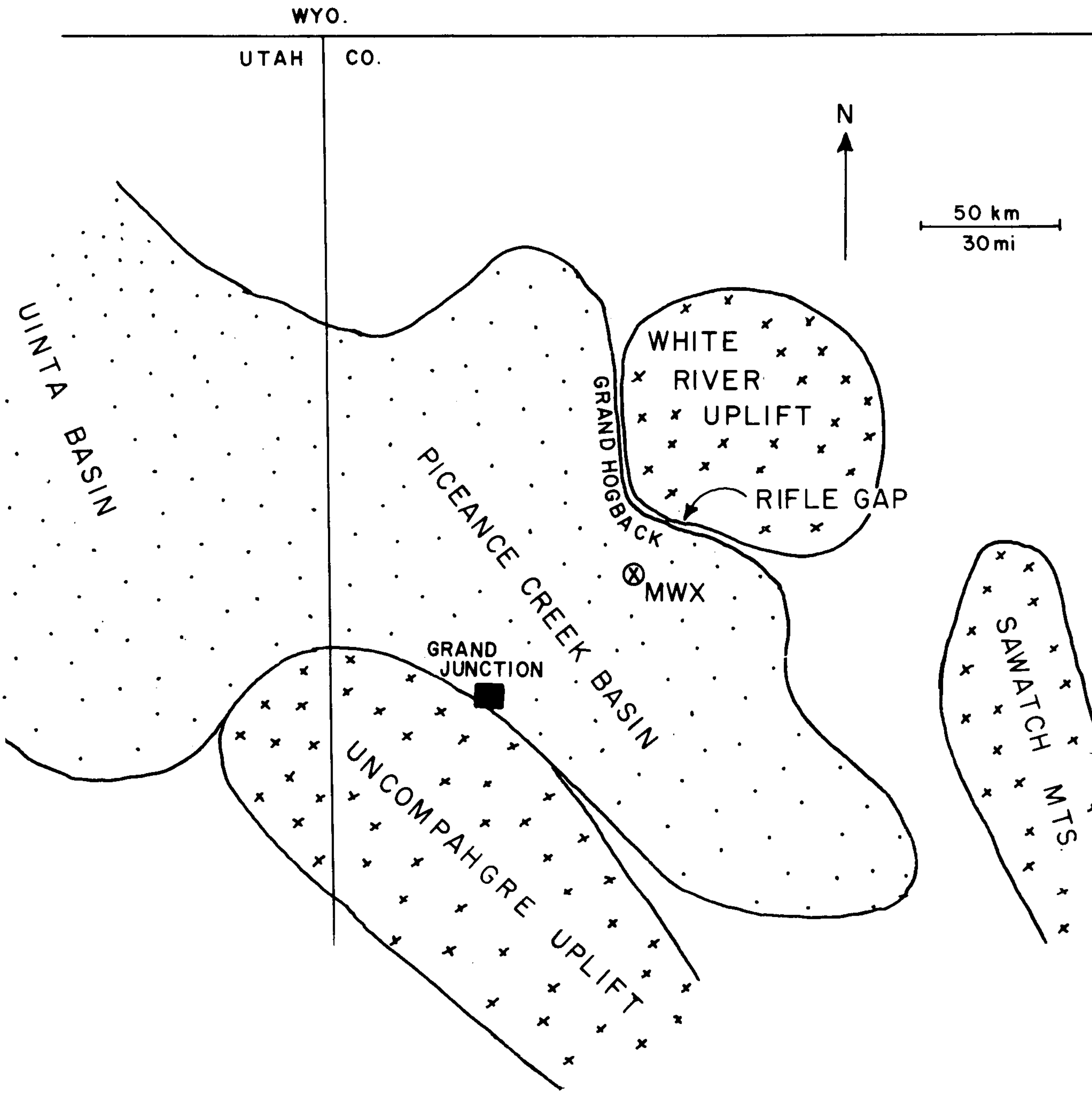

Figure 2. Generalized tectonic framework of northwestern Colorado during Late Cretaceous time.

deposited. Figure 3 summarizes the stratigraphy and timing of events in northwestern Colorado.

The Mesaverde Formation at Rifle Gap

Introduction

The entire Mesaverde Formation is exposed on Route 325, about 10 km (6 miles) north of the town of Rifle. Here Rifle Creek cuts through the Grand Hogback to form Rifle Gap. The outcrop is located at the central part of the eastern edge of the basin. This is the closest outcrop, with reasonable exposures, to the MWX site, which is about 12 miles to the southwest. Mesaverde rocks in this outcrop dip at about 80° towards the south-southwest. Because of this, the terms "above" and "below" in this report refer to stratigraphic position of the rocks, "up" being to the south, or towards the youngest beds in the section. The remains of an irrigation aquaduct can be seen on the eastern side of the gap. Anchoring blocks for the Rifle Gap curtain are present on both sides of the gap, about a third of the way up the hill slope, near the top of the Mesaverde section (at the southern end of the gap). To the north of the Grand Hogback, a broad valley is formed in the soft Mancos Shale between the hogback and the erosion-resistant rocks in the White River uplift to the north.

Figure 4 is derived from the Rifle, Rifle Falls, Silt, and Horse Mountain topographic maps; modifications have been made to update and simplify the maps. The Mesaverde sand bodies which crop out have been marked and numbered for reference purposes in following this guide. Some, but not all, of them can be correlated across the gap. Figure 5 is a simplified measured section through 1650 m (5000 ft) of the Mesaverde Formation and related rocks, which puts the different lithologies and

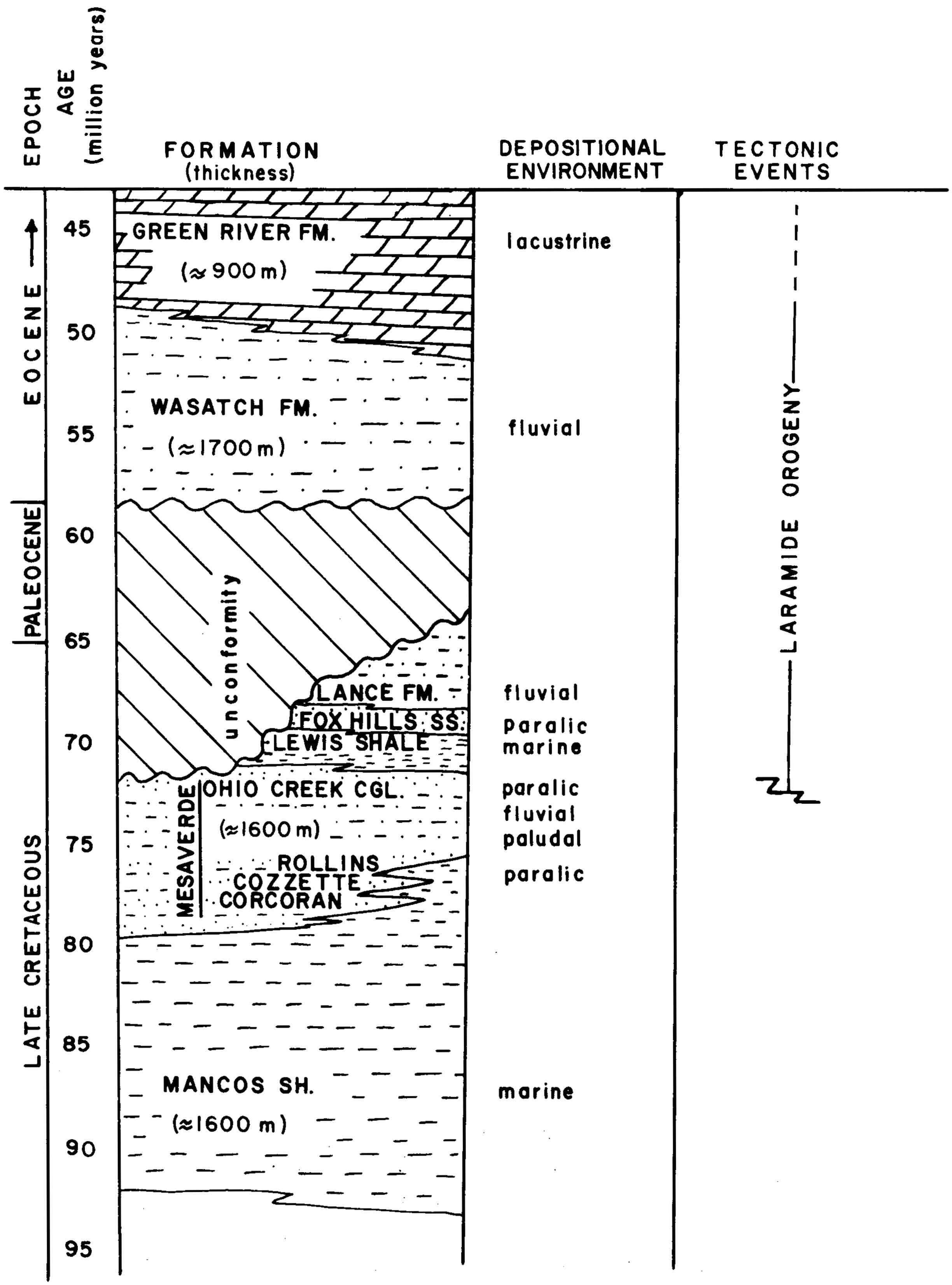

Figure 3. Generalized stratigraphic column of Late Cretaceous-Early Tertiary rocks in the eastern Piceance Creek Basin.

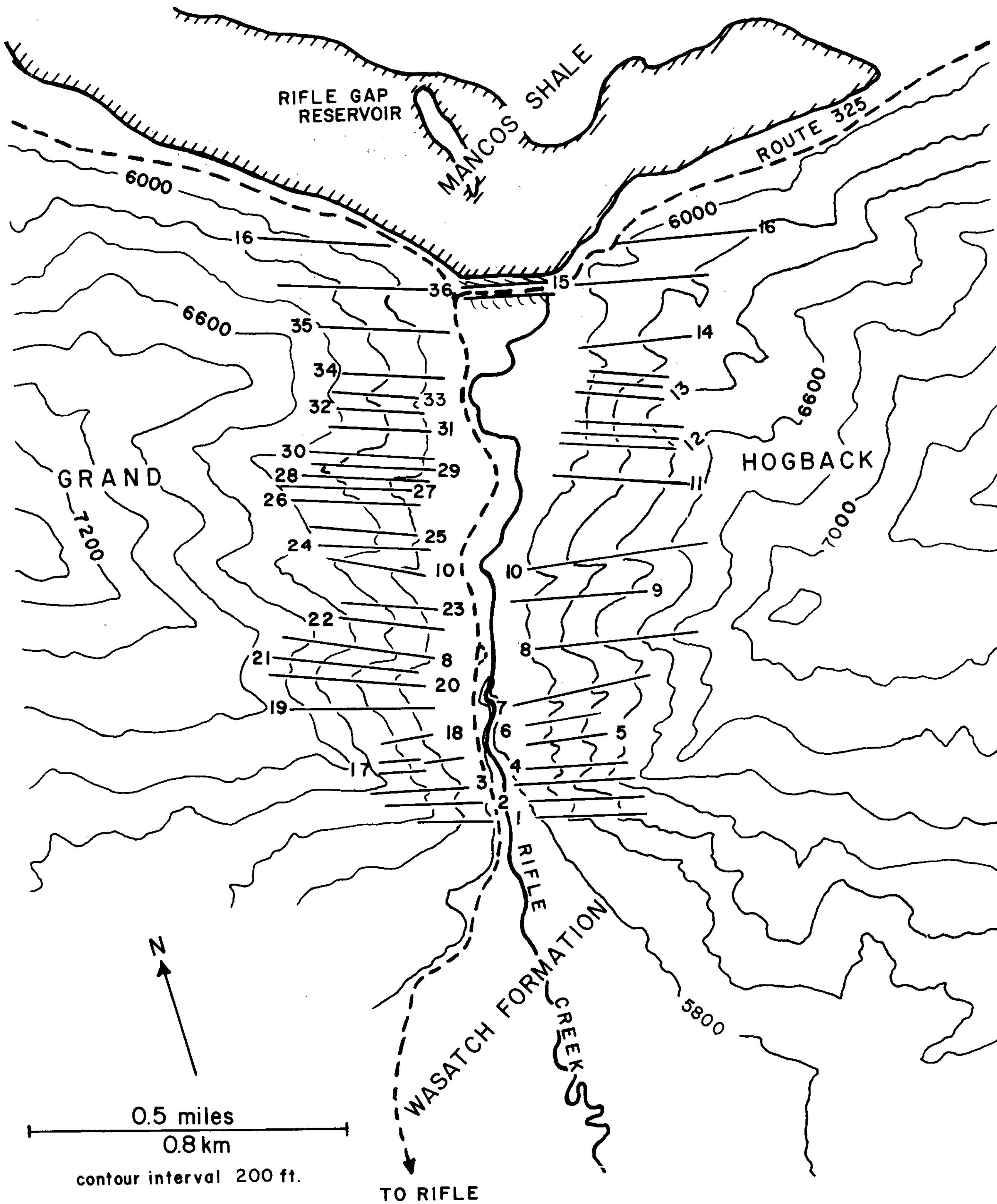

Figure 4. Topographic map and outcrop pattern of Mesaverde rocks in Rifle Gap. Corcoran, lens 16; Cozzette, lenses 36 and 15; Rollins, lenses 35 and paludal lenses 11-13 and 29 to 35; fluvial, lenses 4 to 10, and 17 to 28; marine, lenses 1 to 3; Ohio Creek, lens 1.

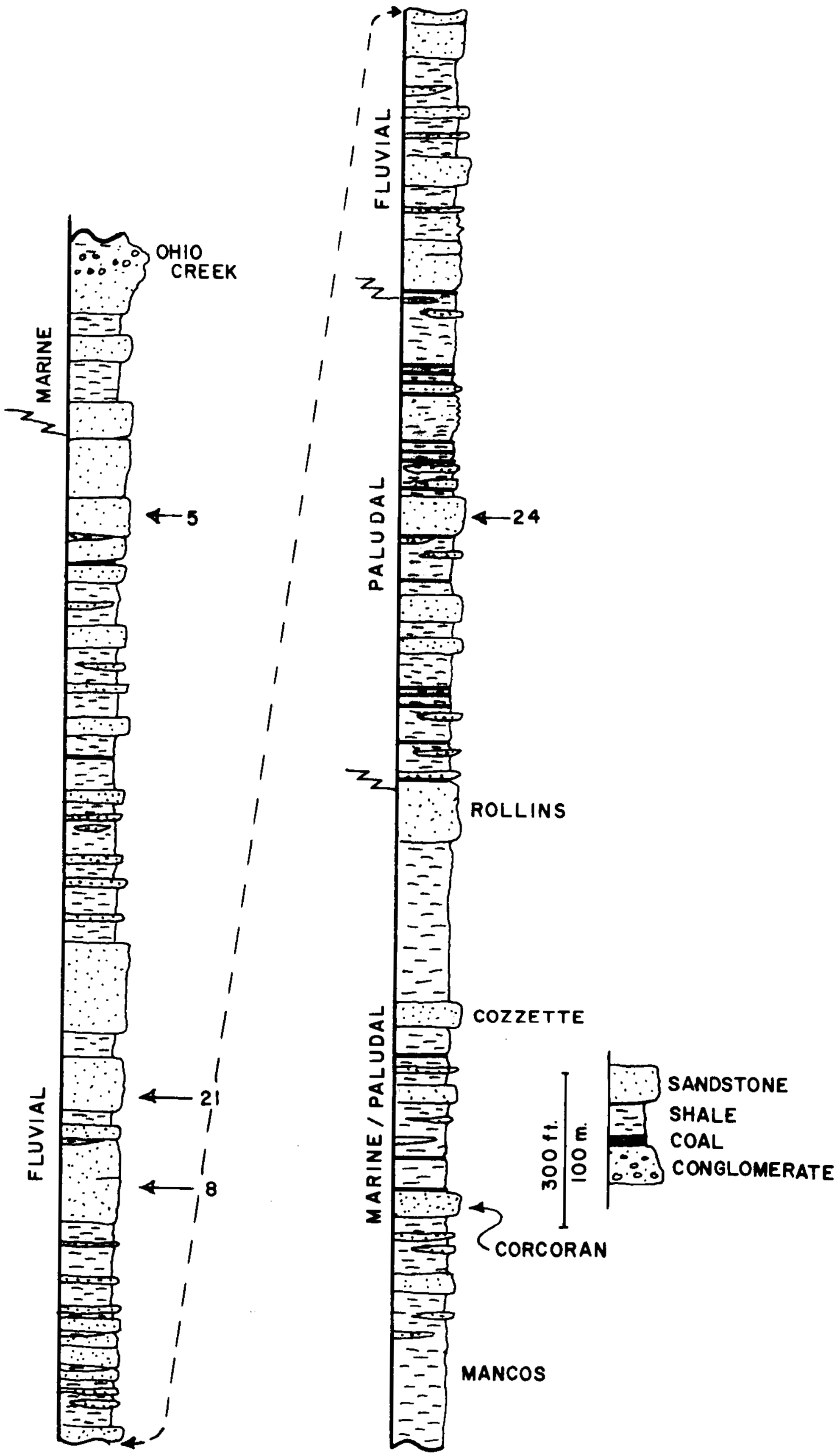

Figure 5. Measured stratigraphic column through Mesaverde rocks in Rifle Gap (modified from Horn and Gere, 1954).

sandstone bodies into vertical perspective. Many of the mudstone intervals are inferred (being covered), and most of the smaller sandstones are not laterally persistent.

Shoreline Blanket Sandstones

The first suggestion of a regressive episode at Rifle Gap is found in the Mancos Shale, where Warner (1964) has inferred that a series of amalgamated, thin sandstones is the distal, offshore equivalent to the Sego shoreline sandstone which is recognized on the western edge of the basin. At Rifle Gap, the inferred offshore equivalents to the Sego member is exposed in the road cut along the northern edge of the hogback, about 400 m (1200 ft) northwest of the Rifle Gap Reservoir dam. The Sego equivalent is overlain by a tongue of the Mancos Shale.

The Corcoran Sandstone member is the first of the blanket shoreline sandstones which can be unmistakably identified. It also can be found in the road cut about 200 m (600 ft) northwest of the dam. At Rifle Gap it is composed of several sandstones interbedded with coals and shales, and is overlain by marine shales.

The Cozzette Sandstone member is also a composite blanket sandstone with associated shales and thin coals, and is well exposed in the road cut at the western end of the dam. A thick oyster-bearing bed at the top of the Cozzette suggests that it may have been part of an offshore barrier island system. The brackish waters of the protected lagoon would have supported the prolific oyster population indicated by the thick shell bed. The last major tongue of the Mancos overlies it, and forms a small valley because of its lack of resistance to erosion.

The Rollins sandstone member is the thickest of the shoreline blanket sandstones at Rifle Gap, being about 40 m (120 ft) thick. It is the last of the named shoreline sandstones, although another occurs about 100 m (300 ft) above it. The Rollins crops out as a white sandstone in the road cut at the first bend to the left in the road downstream from the dam, about 30 m (90 ft) up the road from mile marker 4.

These blanket sandstones were formed in wave-dominated shoreline/delta depositional systems. The structures of these systems at Rifle Gap are best exposed in the Rollins and Cozzette Sandstones. Below the shoreline sandstones, transition zones of thin, alternating sands and shales can be seen. This facies is well exposed opposite the dirt turnout just beyond the east end of the dam, below the Corcoran sandstone. The tracks and trails of marine worms can be seen on the bedding surfaces of many of the rippled sands, and sand-filled burrows sometimes weather out of the shales. The thin sands are turbidity-flow deposits of sands derived from the shoreface, probably during storms (Howard and Reineck, 1981). The intervening shales were deposited as clays settled out of suspension during times of quieter water.

The sandstones get thicker and become amalgamated as they get closer to and grade into, the base of the blanket sandstones. The absence of shales indicates that sedimentation was taking place above storm-surge wave base. Waves from repeated storms removed clays deposited between storms, and reworked the shallow marine sand deposits into "hummocky cross-stratification" (Fig. 6). This type of stratification, composed of undulating but parallel thin beds of sand over a sharp erosional base, is diagnostic of shallow marine environments (Harms et al, 1975).

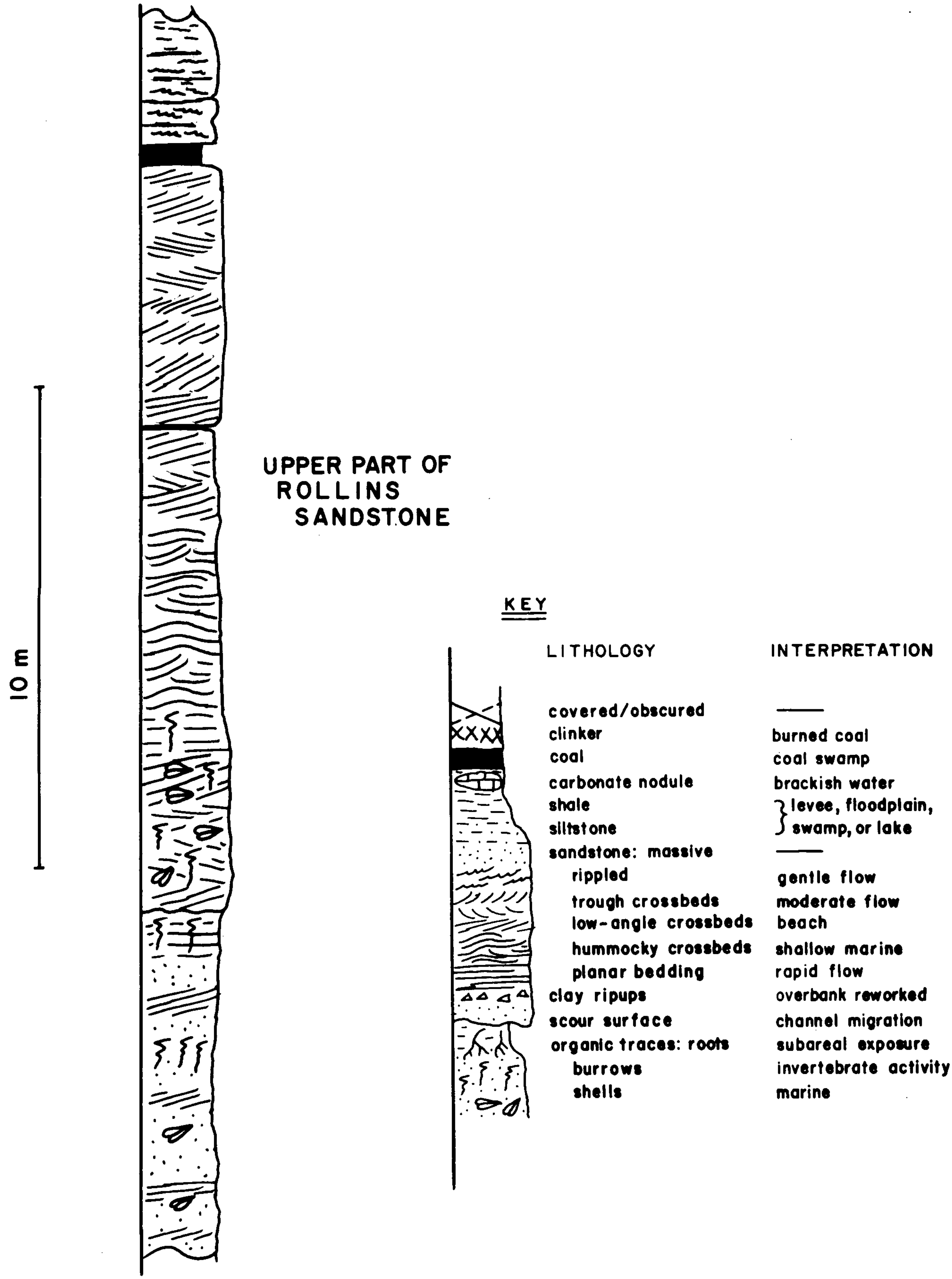

Figure 6. Measured section through upper part of the Rollins sandstone along the road cut at Rifle Gap (lithologic key for this and following sections).

Within the blanket sandstones, Ophiomorpha (Fig. 7), the fossil burrows of marine crustaceans, and fragments of the shells of the marine bivalves Inoceramus (Fig. 8) are common. Near the top of the Rollins, the hummocky cross-stratification and crossbedding of offshore bars give way to the very low angle crossbedding indicative of the swash action of the upper shoreface (beach).

This interval of the Mesaverde Formation from the Corcoran to the Rollins has been called the Iles Formation by Hancock (1925). The overlying paludal and fluvial lithologies he called the Williams Fork Formation. This nomenclature is not in universal usage throughout the basin.

The Paludal Zone

With the continued regression of the interior seaway, the Rifle Gap area eventually became a marshy (brackish) to swampy (fresh water) lower delta plain. Coals, carbonaceous mudstones, and distributary channel sandstones were deposited in this environment. A continued marine influence is demonstrated by the infrequent presence of oyster fossils and siderite nodules, both of which are found in brackish water environments. The coastal plain did not prograde much farther east than the Grand Hogback, since the few deposits of equivalent age present to the east are of entirely marine origin.

Thick coals were deposited in this paludal setting, and are still mined along the Grand Hogback. Most of these coals have been burned and reduced to clinker where they crop out, the fires having been started by lightning, man, or spontaneous combustion. Some seams are still burning, and one peak of the hogback nine miles to the east of Rifle Gap is called Burning Mountain. The heat from the burning coal has oxidized most of the

Figure 7. Photograph of fossil *Ophiomorpha* burrow in shallow marine/shoreline sandstones, lower Mesaverde Formation, Rifle Gap.

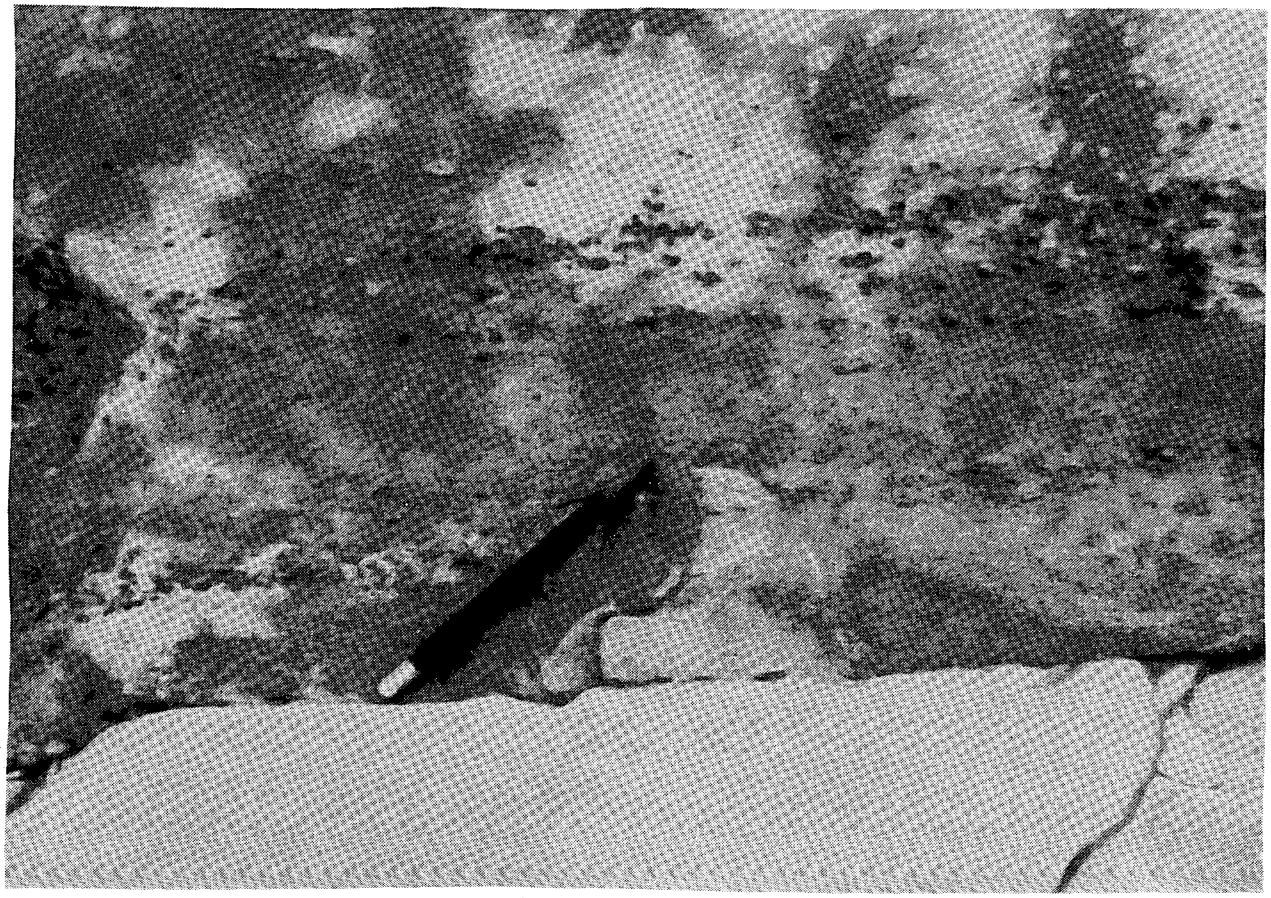

Figure 8. Photograph of fragments of Inoceramus shell in the Rollins sandstone, Rifle Gap.

iron in these deposits at the outcrop, and thus most of the paludal section has a distinctive reddish color along the Grand Hogback. Horn and Gere (1954) have measured 19 individual coal seams in the paludal zone in the immediate Rifle Gap area, two of them almost 3.5 m (11 ft) thick.

The roadcut west of the dam provides the best exposures of the lower 120 m (360 ft) of the paludal deposits. The 20 m (60 ft) of coals, rippled fine-grained sandstones, and burrowed shales above the Rollins Sandstone represents the infilling of a brackish-water marshy environment. A thin (30 cm/1 foot), white, bentonite clay (altered volcanic ash) is located very near the top of this interval.

The overlying 20 m (60 ft) of section is primarily composed of thin rippled sandstone beds which probably represent overbank splay and levee deposits from an adjacent distributary channel. It is covered by a spectacular 5 m (15 ft) seam of clinker. The next 35 m (105 ft) upsection/down the valley has a 13 m (40 ft) thick channel-fill sandstone near the base. (A small fault, probably formed during uplift of the hogback, occurs in the roadcut about 5 m (15 ft) down the road from mile marker 4.) Above it is a muddy interval which probably represents the infilling of a local lake (Fig. 9). The four thin sandstones which interrupted the muddy deposition have very irregular "ball and pillow" structures on their bases, suggesting that the muds were soft and soupy at the time of sandstone deposition.

The succeeding 27 m (80 ft) are more sandstones and mudstones deposited in swamp, levee, and lacustrine environments. Near the top, a series of thin interbedded shales and rippled sands suggest a distal levee deposit (Fig. 10). Fossil roots indicate plant growth during subareal exposure.

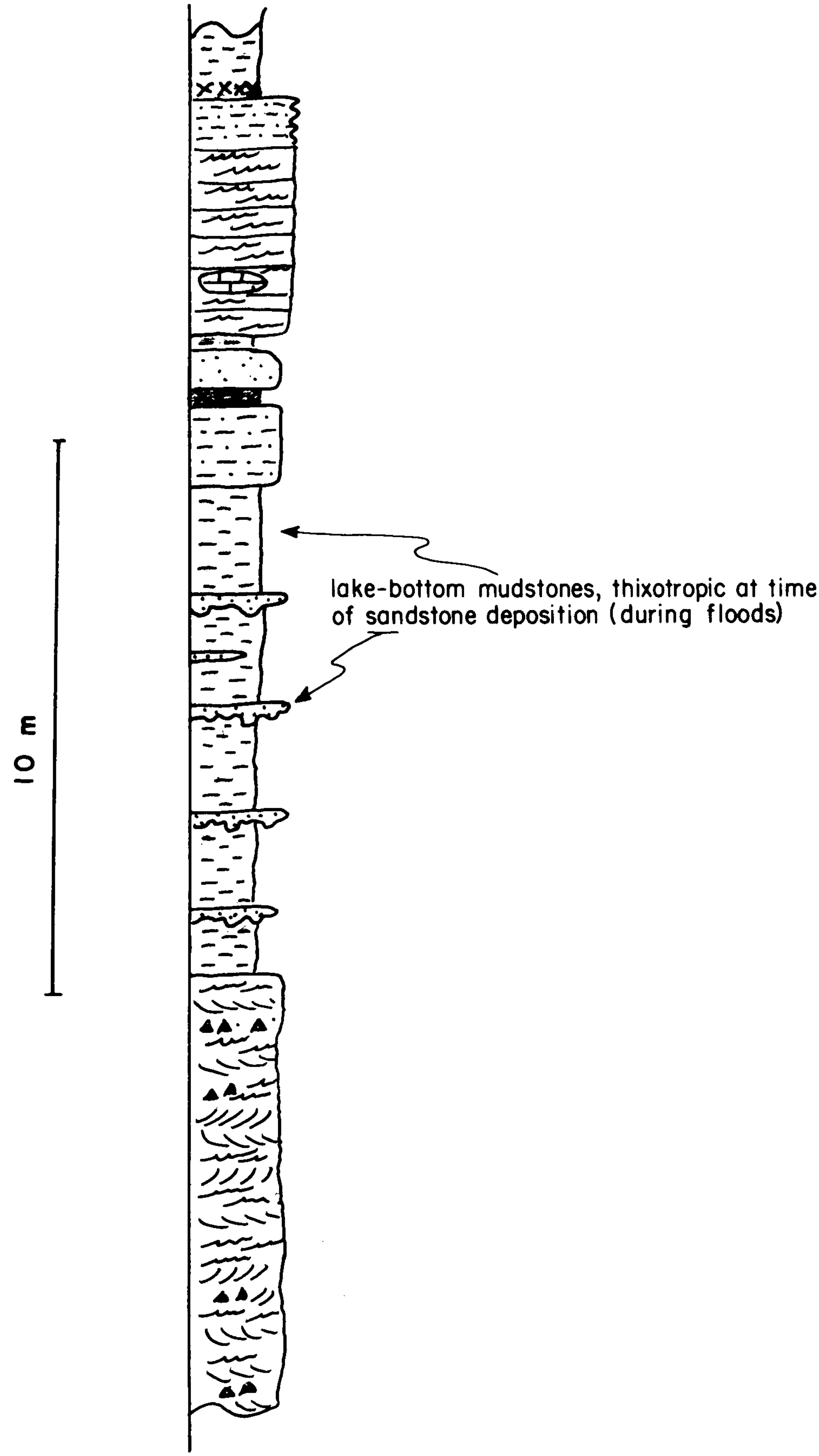

Figure 9. Measured section through channel and lake deposits of the paludal zone of the Mesaverde Formation; road cut at Rifle Gap (see Fig. 6 for key).

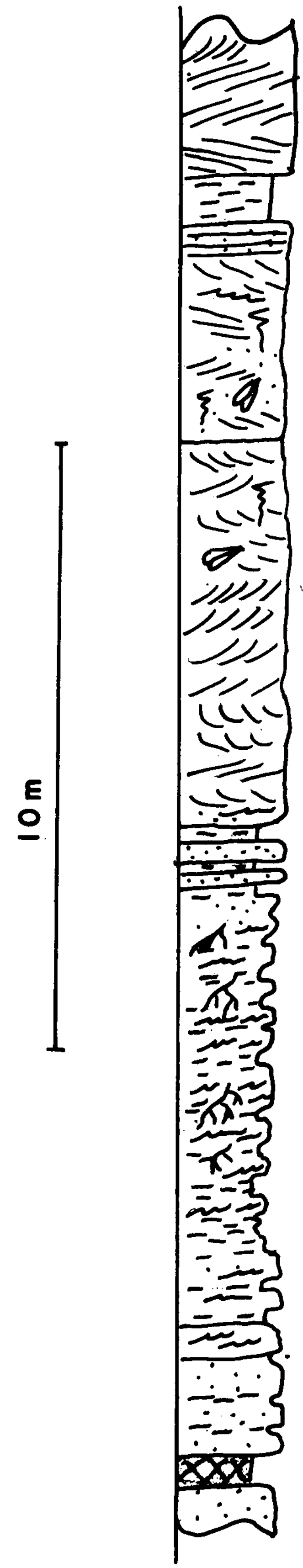

Figure 10. Measured section through levee and shoreline deposits of the paludal zone of the Mesaverde Formation; road cut at Rifle Gap (see Fig. 6 for key).

It is abruptly overlain by the last of the shoreline/blanket sandstones, about 14 m (42 ft) thick, which is located just below a valley of obscure deposits.

The remainder of the paludal interval is obscure. Based on the presence of red outcrops, total thickness of the paludal zone is about 310 m (890 ft) ending in the vicinity of lenses 28, 29, where the telephone wires come down off the hillside onto the valley floor. The coal-bearing interval probably extends further upsection, but the coals become thinner and less pure with the transition into the upper delta plain (purely fluvial coastal plain) environment, and are covered and unburned. Horn and Gere (1954) note coals occurring up to 350 m (1060 ft) above the Rollins (see Fig. 5).

Lens group 24/25 (located just west of a sharp bend to the east in the road), is within the transitional zone, and is located in the lower part of a gas-bearing interval in the Mesaverde Formation of the Rulison gas field (which surrounds the MWX site). In outcrop on the western slope of Rifle Gap (Fig. 11), this group of sandstone bodies shows a variety of morphologies in two dimensions. The sandstones are often obscured by lichen growth and/or talus cover, and it has not been possible to measure crossbedding to determine paleoflow directions within them. As a rule, the sandstones have irregular erosional bases. Their edges, where visible, finger out into the adjacent mudstones and levee deposits. Sideritic carbonate nodules are found in the rare exposures of the mudstones, suggesting brackish water was still present from time to time.

The Fluvial Zone

The fluvial zone extends from the top of the red paludal zone to the base of the marine section, and is about 780 m (2450 ft) thick. It has

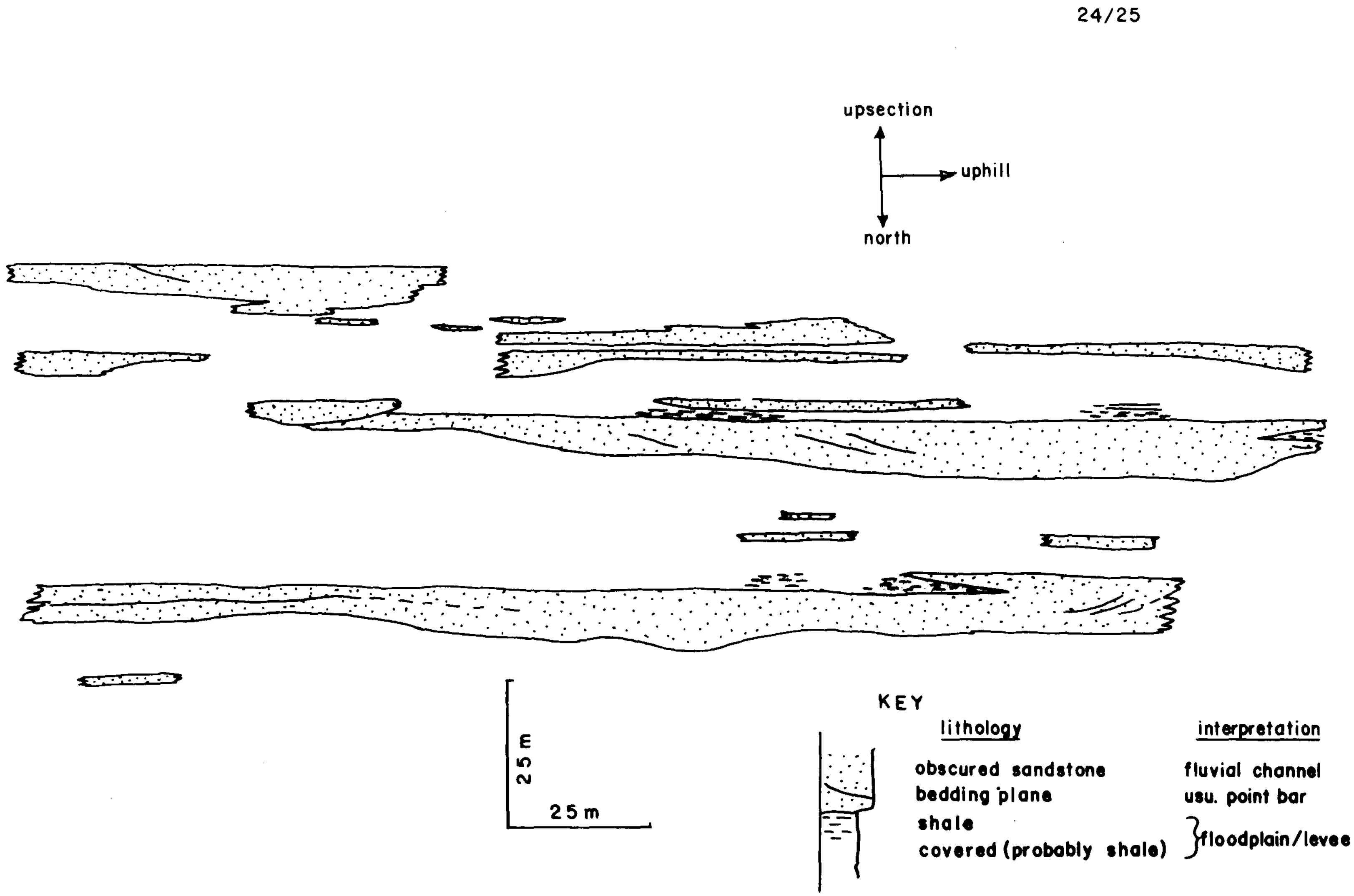

Figure 11. Outcrop of lens group 24/25, west side of Rifle Gap (lithologic key for this and following sandstone lens schematics).

intervals of high percentage sandstone alternating with intervals of high percentage shale. The basal 425 m (1300 ft) of this zone is a gas-bearing zone in the Rulison field, and is of major interest in the MWX.

Sandstone lenses in this interval have apparent widths many times their thickness, and they are composed of sediment from multiple episodes of deposition. The thickest sandstone, and best example of the depositional environment of this interval is lens 8. Where it crops out on the western slope of Rifle Gap, nearly opposite the rest area , lens 8 shows a composite nature of numerous discrete and amalgamated sandstones concentrated along one horizon (Fig. 12).

This is interpreted as a meander belt horizon, where a fluvial system was in residence for an extended interval of time, allowing it to meander back and forth, and to leave extensive sandy deposits similar to those depicted in Fig. 13. Most of the other lenses at Rifle Gap are products of less residence time, and are therefore more isolated within the overbank mudstones.

Fig. 14 shows a detailed measured section through a less obscure part of the sandstone of lens 8. At least eight depositional events are represented here, where rippled zones and shales indicate the last waning flow of an event. Fig. 15 is a detailed section through the finer-grained levee deposits adjacent to the channel sandstones. Generally, a fining-upwards couplet of sandstone and shale are representative of one overbank flood event. Near the downhill end of lens 8 (Fig. 12), a tree trunk can be found in growth position in the levee sediments. Abundant soft sediment deformation in the channel sands, and bedding-plane tracks and trails in the overbank muds, indicate a high water table during deposition.

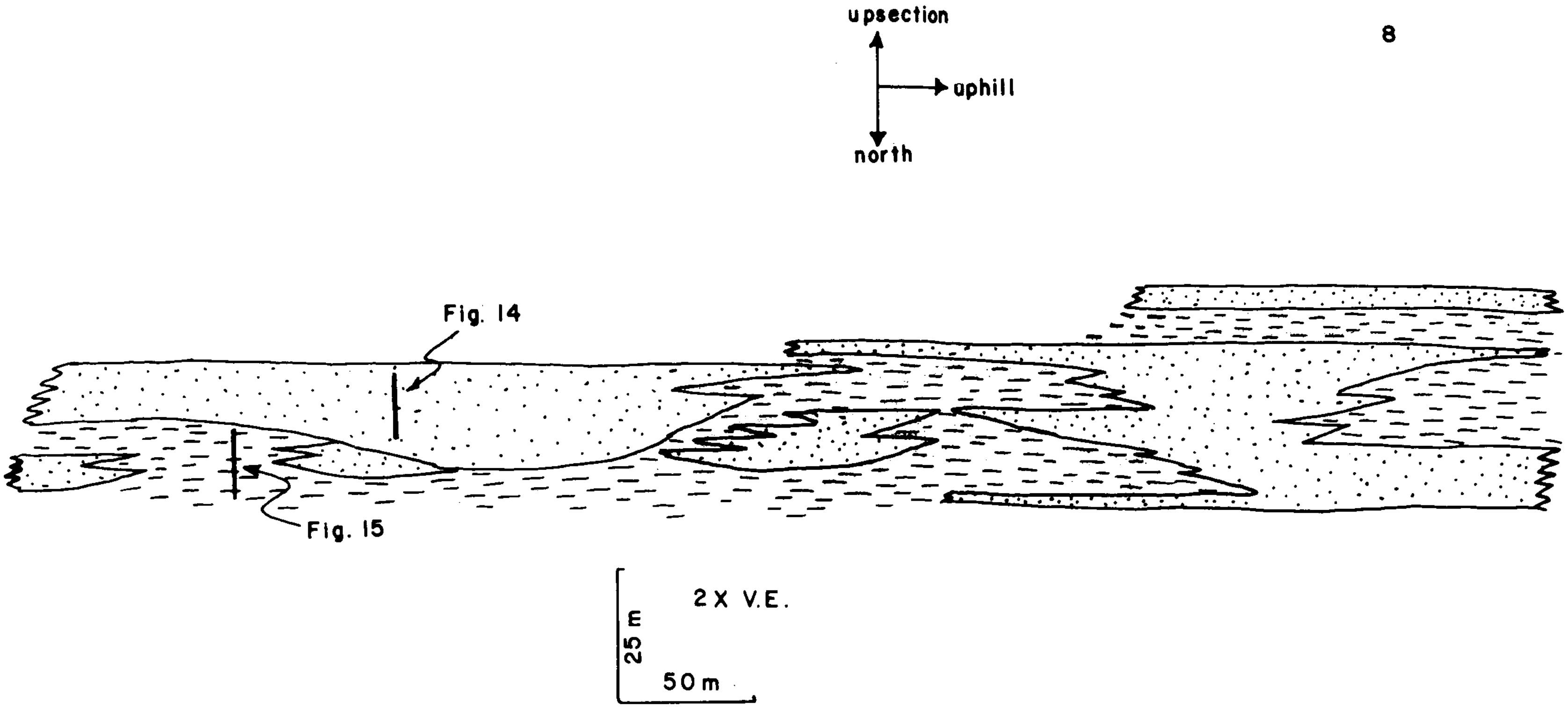

Figure 12. Outcrop of lens 8, west side of Rifle Gap (V.E. = vertical exaggeration; see Fig. 11 for key).

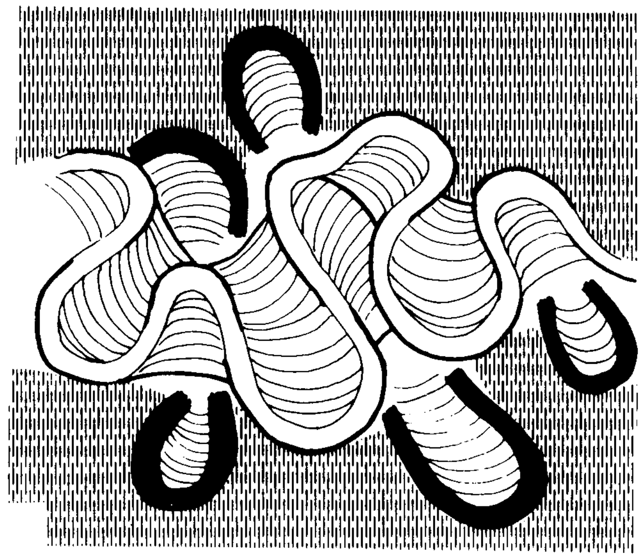

Figure 13. Construction of a meander belt horizon (from Collinson, 1978, Fig. 1-B).

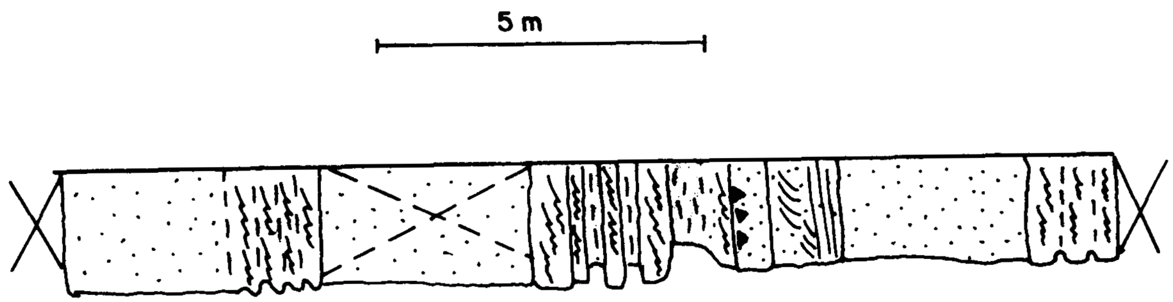

Figure 14. Detailed section through fluvial channel sandstone of lens 8, Rifle Gap. (See Fig. 6 for lithologic key, Fig 12 for location.)

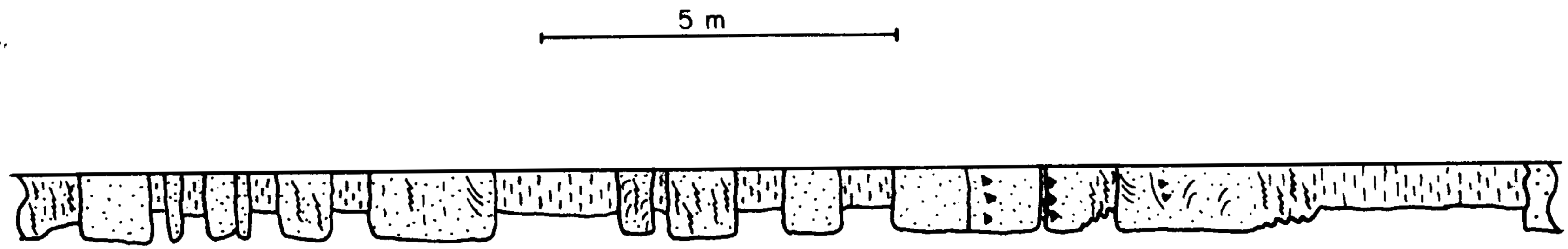

Figure 15. Detailed section through overbank and levee deposits associated with lens Rifle Gap. (See Fig. 6 for lithologic key, Fig. 12 for location.)

In lenses 20 and 21, just above lens 8, some of the sedimentary structures which comprise these sand bodies are visible. Fig. 16 shows the lateral accretion point bar structures in the uphill end of the lower lens. The break in the upper lens is suggestive of the same feature, which was abandoned, filled with mud, and then reactivated at a slight offset.

These features are well displayed in lens 5, near the top of the section, on the eastern slope of Rifle Gap (Fig. 17). Such features arise from point bar migration on the inside of meander bends as illustrated in Fig. 18. Actual flow of water and sediment was at right angles to the migration of the lateral accretion surfaces. If binoculars are used, these features in lens 5 may be picked out from the road, at the point where the telephone wires cross it. They show as a shingled effect on the top surface of the sandstone (the surface on the left hand side of the "channel" between two sand bodies, looking east across the river).

A coal seam 76 cm (2-1/2 ft) thick and of limited extent (Horn and Gere, 1954) has been mined from close below lens 5. The tailings from the mines can be seen on both sides of the gap. It is the highest coal in the Mesaverde Formation at Rifle Gap, and is considerably above the coals of the paludal zone.

The Marine Zone

The Lewis transgression of the interior seaway deposited shoreline blanket sandstones and marine shales over the Mesaverde Formation in the northern Piceance Creek basin. From Meeker south, including Rifle Gap, deposits of this transgression have not been recognized in the Piceance Creek basin, although they are present in many places from Alberta to New Mexico. It is felt, however, that the uppermost 100 m (300 ft) of Mesaverde

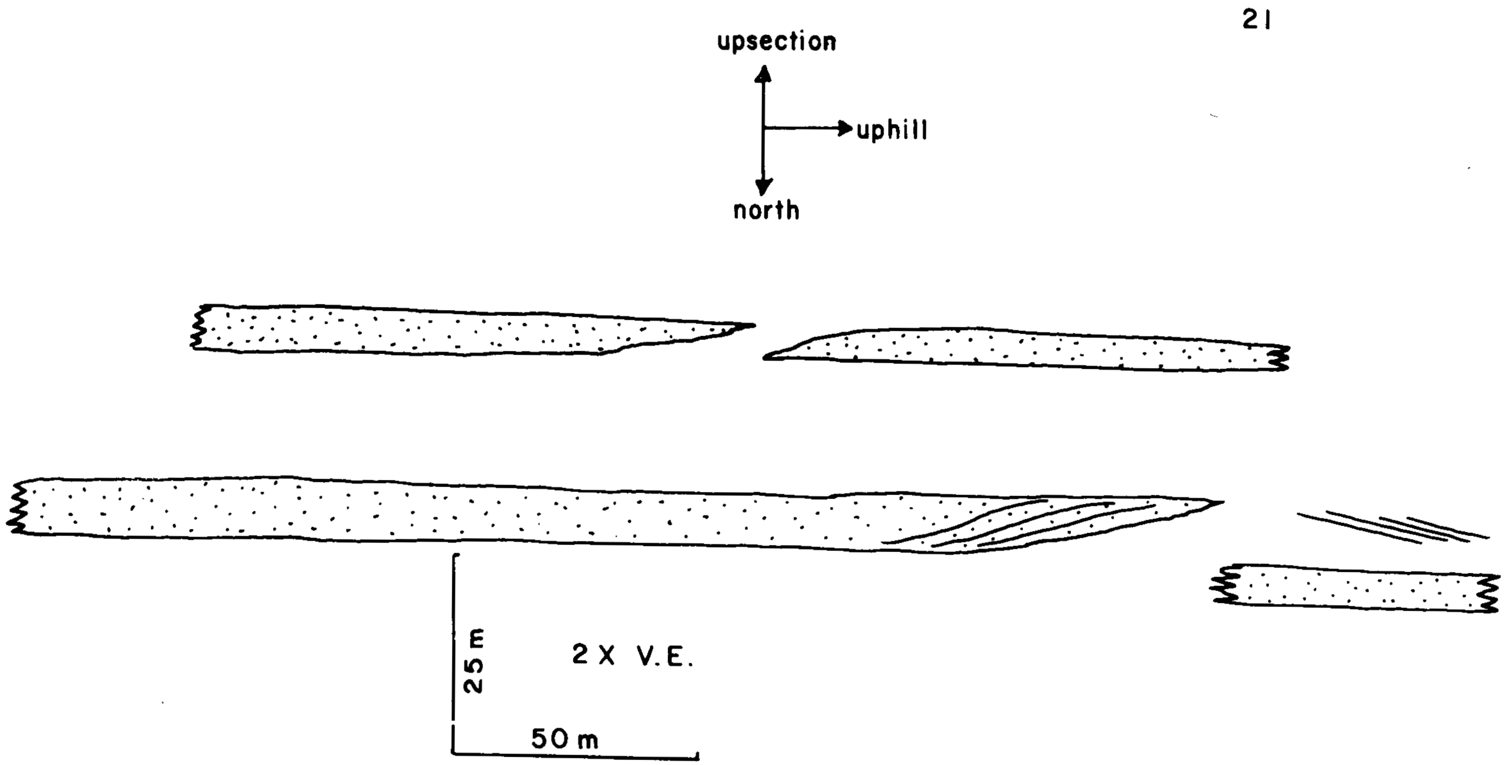

Figure 16. Outcrop of lenses 20, 21, west side of Rifle Gap. (See Fig. 11 for key.)

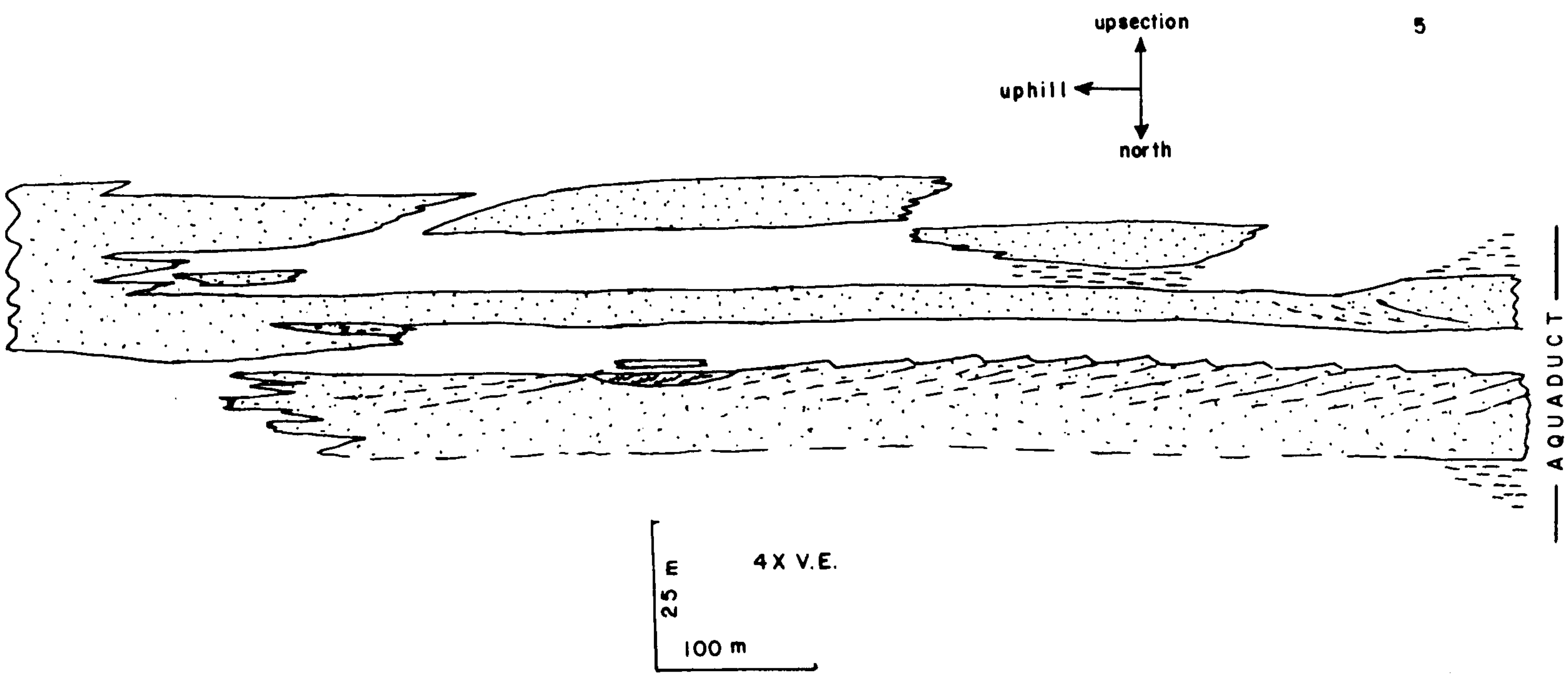

Figure 17. Outcrop of lens 5, east side of Rifle Gap. (See Fig. 11 for key.)

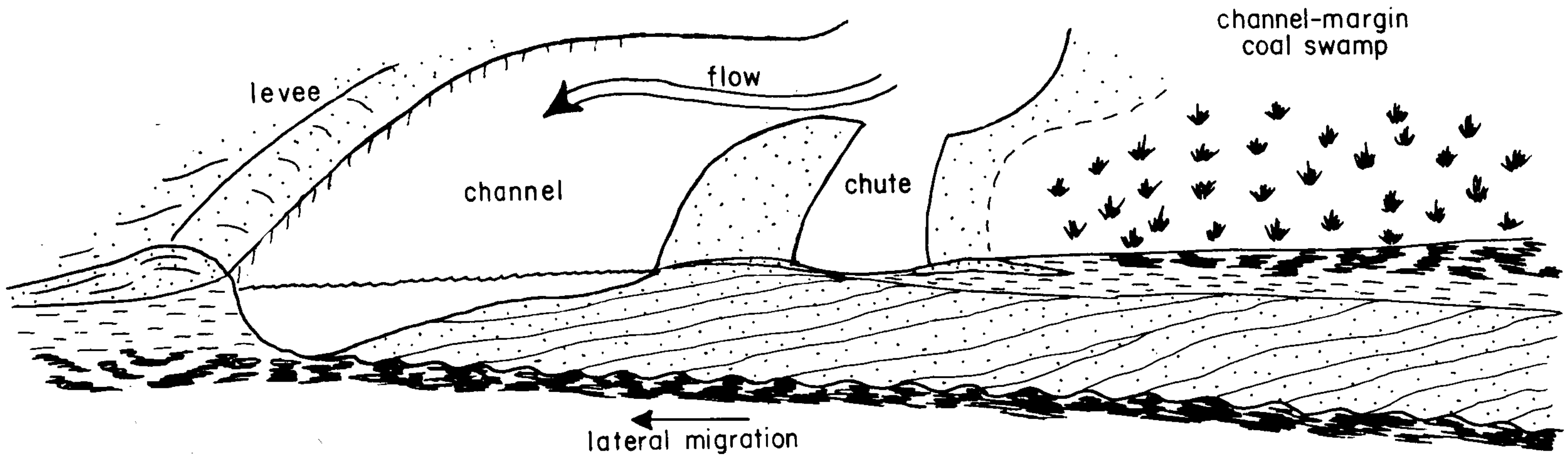

Figure 18. Model of point bar formation and subsequent lateral migration in a meandering river (adapted from Miall, 1979, Fig. 4).

rocks at Rifle Gap are remnants of such deposits. The extensive sandstones found in this relatively sandy interval (lenses 1, 2, and 3) are probably transgressive marine/shoreline sandstones. They were overlain by more marine sediments (shales?) prior to erosion and the formation of the unconformity/ fossil weathering profile that occurs between the Mesaverde and Wasatch Formations (Johnson and May, 1980).

Interpretation of these sandstones as marine is based in part on the presence of Teredos (fossil shipworm-type burrows, Fig. 19) found in the fossil wood in the sandstones. None of these fossils are visible from the road, but excellent examples can be seen at the base of lens 3 if time and energy are available for climbing the hillslope. However, lenses 1, 2, and 3 are on private land, and permission should be obtained before climbing to them. (All other outcrops described here are on BLM land.)

The relatively blanket-like geometry of these sandstones, and the dominance of low-angle and some hummocky crossbedding, supports a marine origin, as does the recently discovered presence of small amounts of glauconite in the sands of lens 3 (Stein, pers. comm., 1981). Glauconite is an iron-bearing clay mineral which usually occurs in fecal pellets of marine organisms.

The Ohio Creek conglomerate has been recently reinterpreted to be the uppermost member of the Mesaverde Formation (Johnson and May, 1980). Previously it had been considered to be the basal member of the overlying Wasatch Formation, of Eocene age, but the pollen content of associated shales has proven to be of Cretaceous age.

The Ohio Creek conglomerate is exposed high up on the eastern side of Rifle Gap. Better and more easily reached exposures occur in the stream bed

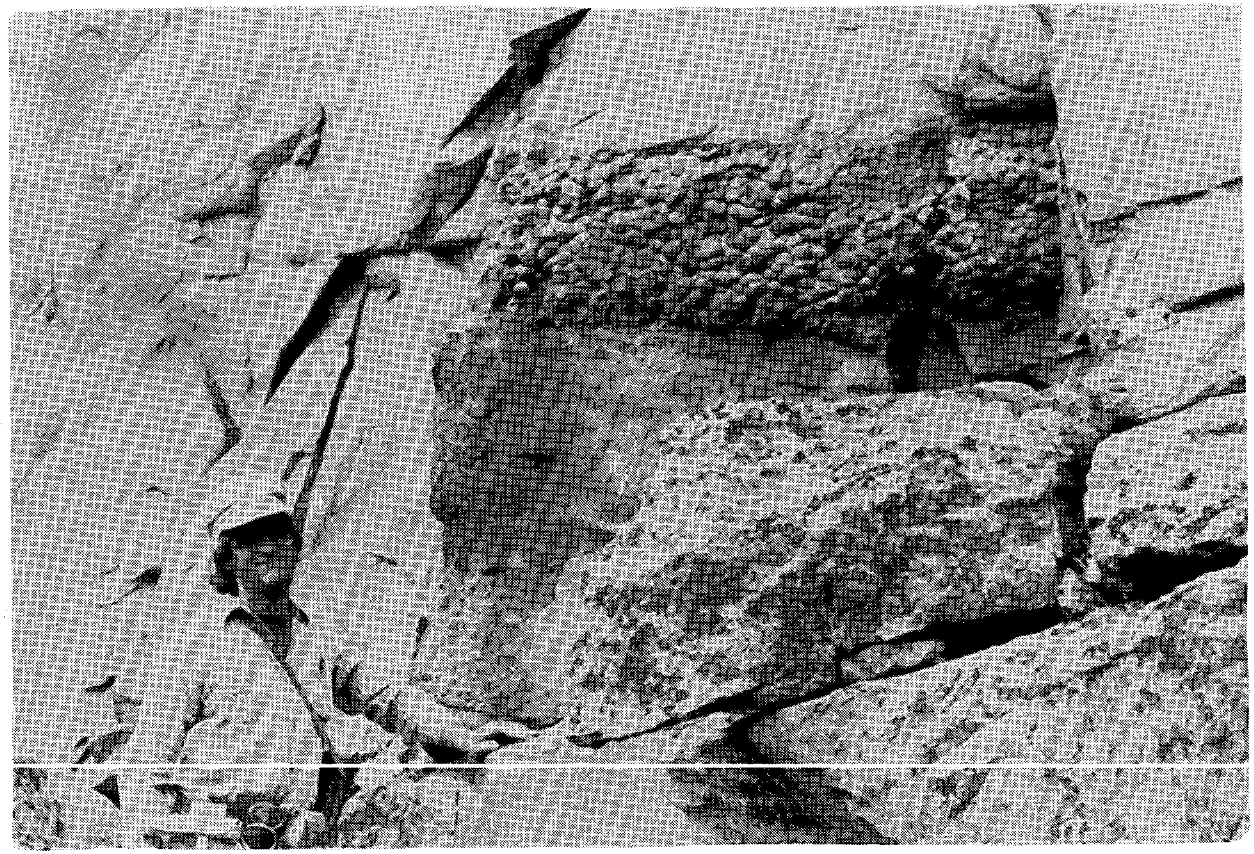

Figure 19. Photograph of <u>Teredo</u> burrows in fossil tree trunk, lens 3 (marine zone), Rifle Gap.

of North Canyon, an incipient gap in the Grand Hogback a mile west of Rifle Gap. It is accessible by the dirt road that leads up to the abandoned North Canyon coal mine.

Sediments of the Ohio Creek conglomerate were probably derived from the Sawatch Mountains, to the southeast (Fig. 2). The outcrop in North Canyon suggests it was deposited as a pebbly shoreline, part of the marine upper Mesaverde Formation.

The Wasatch Formation

The variegated mudstones, and conglomeratic sandstones of the Wasatch Formation are exposed on the Grand Hogback just south of the entrance to Rifle Gap. These fluvial deposits contain discrete lenticular channel sands, fossil soil horizons, and mammalian fossils. They produce gas in the Rulison field.

The Relationship of Rifle Gap Outcrops to the MWX

The "nonmarine" part of the Mesaverde Formation (from the top of the Rollins to the top of the formation) thickens from about 2500 ft near Debeque, in the western part of the basin, to about 4000 feet in the subsurface near Rifle Gap in the east. Some of this thickness variation may have been caused by erosion. Between these extremes near the MWX area, it is about 3500 ft thick (Granica and Johnson, 1980). Horn and Gere (1954) measured this part of the section at Rifle Gap as 3700 ft thick, and remeasurement during this study indicated a thickness of 1195 m (3920 ft). The apparent thinning of the Rifle Gap section compared to the adjacent subsurface thickness of 4000 ft, may have been caused by structural complications during the abrupt uplift of the hogback. If so, most of the deformation probably took place in the less competent shales, which are obscured at Rifle Gap.

A somewhat thicker section at Rifle Gap than at MWX probably implies a slightly higher percentage of claystone at Rifle Gap; where the Mesaverde is only 2500 ft thick on the western edge of the basin, outcrops show a significantly higher percentage of sandstone. Sandstone beds in MWX core may be somewhat thicker than at Rifle Gap, following the same general east-west trends, but comparison of sandstone percentages and thicknesses will be difficult because of the incomplete exposure in the gap.

The environment of deposition changed across the Piceance Creek basin in Late Cretaceous time, from braided fluvial systems on the west side (Young, 1981, oral communication), to predominantly meandering systems on the eastern edge (this study). The position of MWX close to the eastern exposure suggests that it is most analogous to the latter. Study of the core should confirm or modify this conclusion. In general, grain size should decrease, and organic content should increase eastward across the basin as distance from the highlands increases.

Studies of the outcrops suggest that the fluvial sandstone bodies encountered in MWX will be point bar deposits for the most part. Calculations using the point bar deposit dimensions may suggest the sizes of the rivers which deposited them. Many sand bodies will be interconnected; others will be isolated within the muddy/shaley deposits. Sand body shapes will be the erratic, arcuate scrolls of point bars in a meandering fluvial system, and consistent dimensions and orientations are not expected. The larger-scale, composite, fluvial meander belts may trend generally northwest-southeast in the lower sections. However, they may change to a more northeast-southwest orientation upsection, due to the changes in geography that accompanied the local Laramide uplifts.

Continuous sandstone bodies on the order of 200-1000 m (600-3000 ft) minimum lateral extent are present at Rifle Gap. This suggests that most of the sandstones encountered in MWX-1 will also be encountered in the MWX-2 well, which is offset by only 41 m (135 ft), although thicknesses may vary.

In general, the exposures of Mesaverde Formation at Rifle Gap are the closest, and therefore most similar to, the rocks that will be encountered at MWX.

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