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An Approximation of Continuity of Lenticular Mesaverde Group Sandstone Lenses Utilizing Close-Well Correlations, Piceance Basin, NW Colorado

by Richard E. Peterson, CER Corporation
Julie B. Kohout, CER Corporation

ABSTRACT

Mesaverde Group sandstone units in 13 closely-spaced wells in the central and southern Piceance Basin of Colorado were correlated utilizing wireline log response quantitatively and qualitatively. Based on these correlations, the environmental subdivisions of the Mesaverde Group were characterized as follows:

- Paralic (upper mixed-marine) zone, occuring in the uppermost Mesaverde Group, includes thick sandstone units which are interpreted to be regionally continuous.
- Fluvial zone, containing point-bars 20 to 30+ ft thick, is interpreted to be correlatable to a maximum of 6,800 ft.
- Paludal zone has insufficient data to adequately characterize the sand units. However, 63 percent of the units are correlatable across at least 139 ft.

An approximation of the dimensional characteristics of Mesaverde sandstone units has potential applications in designing hydraulic fracturing treatments and estimating gas reserves more accurately.

INTRODUCTION

Within the Piceance Basin of northwestern Colorado, as shown in Figure 1 with study well location areas, the Upper Cretaceous Mesaverde Group produces gas from multiple sandstone reservoirs. These Mesaverde reservoir units are believed to contain large volumes of gas - up to 40 trillion cubic ft - yet are often non-commercial because of low production rates. These low rates are a function of very low permeability and limited reservoir size due to discontinuous, lenticular sandstone bodies. An approximation of the continuity and dimensions of Mesaverde reservoirs should be useful in designing more efficient hydraulic fracturing treatments and, possibly, a more accurate estimate of gas reserves in the reservoir.

References and illustrations at end of paper.

GEOLOGIC SETTING

To assess adequately the continuity of Mesaverde sandstone bodies in the Piceance Basin, the style in which the sandstones were deposited was characterized. As outlined by Lorenz,[1] the Mesaverde deltaic sediments were deposited into an interior seaway, as shown in Figure 2 (after Mallory, et al),[2] during most of Late Cretaceous time. The Mesaverde Group can be subdivided into contemporaneous depositional systems which form a "systems tract",[3] as illustrated by the example in Figure 3 (from Fisher and McGowen).[4] In the Piceance Basin from west to east, the tract is composed of medial fan, upper delta plain and shoreface facies. The medial fan facies is characterized by braided stream deposits. Seaward, on the lower energy environment of the upper delta plain, meander belts dominate with deposition of point-bar sandstones and overbank mudstones. Lorenz has termed this the fluvial zone of the Mesaverde. Seaward, on the lower delta plain, swampy conditions prevailed with deposition of coals, mudstones and distributary channel fill sandstones and is termed the paludal zone of the Mesaverde. At or near the wave dominated shoreline, barrier-bar sequences developed and formed composite, blanket-like sandstone deposits. These shoreface sandstones of the lower marine zone are presently known as the Castlegate, Sego, Corcoran, Cozzette and Rollins Sandstones.

Continued seaward progradation of each of these facies resulted in a vertically stacked sequence, as shown in the stratigraphic column of Figure 4. In addition, marine-influenced sandstone units have recently been interpreted by Lorenz[5] to have been deposited over the fluvial section of the Mesaverde. This new interpretation is substantiated by palynological analyses of samples from the MWX-1 well (13 miles southwest of the outcrop) from the top of the Mesaverde Group.[6]

The areas studied in this report were the Rulison Field and Rio Blanco Unit, both of which were shown in Figure 1 (from Dunn).[7] The geologic setting in both of these areas is considered to be similar during

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deposition of the Mesaverde Group.

Only the paralic (upper mixed-marine), fluvial and paludal zones of the Mesaverde are examined in this report.

SAND BODY MORPHOLOGY AND DIMENSIONAL CHARACTERISTICS

In the studied sections, sand bodies are blanket-like deposits in the paralic (mixed-marine) zone, point-bars (predominantly) in the fluvial zone and channel-fill sandstones (predominantly) in the paludal zone. With these basic assumptions, each "ideal" sand body type can be dimensionally characterized.

In the upper marine zone, delta/shoreline sand aprons are anticipated to be extensive and blanket-like in overall geometry. There may be some discontinuity where distributary channels or muddy bars and marshes dominated the local environment.

In the fluvial zone, point-bar morphology is directly related to stream flow. Large discharge streams have greater meander lengths, are deeper and wider, and thus, form larger point-bars than smaller streams. Measurement of actual streams has shown that thickness of point-bars can be used to give an indication of stream size and meander length. One-half the meander length would, thus, be an approximation of one dimension of the point-bar. Empirical relations developed by Swanson[8] indicate, for example, that a 25 foot thick point-bar should have a one-half meander length of 2,900 ft.

From literature of outcrop studies in the Piceance Basin, Knutson[9] postulated a typical length: width:thickness ratio of 190:180:1 for sickle shaped (chute cut-off) point-bar sands in the lower Fort Union Formation. Assuming similar hydrodynamics, this ratio may also be applied to the fluvial Mesaverde. A 25 foot thick unit, for example should have a length of 4,750 ft and width of 2,000 ft.

Lorenz[1] made the observation at the Rifle Gap outcrop that lenses from the Mesaverde fluvial zone have apparent widths many time their thickness with sandstone bodies ranging from 600 to 3,000 ft minimum lateral extent.

As shown in Figure 5, active meander belt point-bars do not have their long dimensions in any preferential orientation. Also, it is likely that the dimensions of original point-bars in an active fluvial system will be preserved because of cut and fill processes. Thus, consistency of orientations and dimensions is not expected in the subsurface. Figure 7 is an example of the irregular spatial relationships of individual sandstone lenses found in the fluvial Mesaverde.

Channel-fill sandstone body morphology characteristically has length much greater than its width.[10] Generally, the width of the channel in which it originated and its length are dependent on the local conditions of burial and subsequent erosion. Knutson[9] estimated that the typical Mesaverde channel-fill sand body has a length:width:thickness ratio of 140:14:1 with the length:thickness ratio ranging from 87:1 to 208:1.

METHODS AND RESULTS

To approximate the continuity of subsurface Mesaverde sandstone units in the Piceance Basin, 13 closely-spaced wells, with significant penetration into the Mesaverde Group, were chosen in the Rulison Field and the Rio Blanco Unit. Based on wireline log responses, sandstone units were correlated in the wells which were spaced between 139 to 10,400 ft apart. Based on the distance between wells, an approximate dimension can be assigned to correlative sandstone units. In this study, correlative sand units are interpreted to also be continuous between wells. These correlated units were subdivided into genetic paralic (mixed-marine), fluvial and paludal groups where possible. The results of the close-well correlations are as follows:

Rulison Field Correlation Analyses

MWX-1 and MWX-2 Correlations. The MWX-1 and MWX-2 wells, drilled as part of the Department of Energy's Western Gas Sands Project to develop and improve technologies for producing tight-sand gas, are spaced 139 feet apart, as shown in Figure 8. Both wells penetrated the entire Mesaverde section and were logged under strict quality control guidelines.

Because of the high quality of digitized data, the sand units were selectively chosen by computer analysis. The following discriminating criteria were applied:

- shale volume must be less than 35 percent from corrected gamma ray log measurements.
- corrected bulk density must be between 2.60 and 1.80 gm/cc, which is approximately equivalent to porosities 5 percent or greater; and
- thickness of the sand must be at least 8 ft.

Because of the very close well spacing (139 feet), the sand units continuous across both wells were expected to maintain similar character and log responses. Thus, to determine the degree of similarity of correlated sand units, the character of the resistivity, bulk density and gamma ray logs was examined. These log responses were chosen because they represent unique correlation parameters for an individual sand lens where bulk density (ρ_b) is related to porosity, resistivity (R_t) is related to reservoir fluid content, and gamma ray response (GR) is related to clay volume and reservoir quality.

The log responses were related by a single equation:

$$\frac{(\rho_b \times GR)}{R_t} = \begin{matrix} X_1 \text{ for MXW-1} \\ X_2 \text{ for MWX-2} \end{matrix}$$

Results (X_1 and X_2) of this equation for each foot of each sand unit in MWX-1 and MWX-2 were accumulated. The ratio of the cumulative X_1:X_2 for correlative sandstone units yields a quantitative estimate of the degree of similarity. For example, correlated reservoir units having identical log responses for R_t,

σ_b, GR and the same thickness will equate to a perfect similarity of 1.0. Arbitrary, but relative labels of poor, fair, good and excellent can therefore be assigned to similarity of correlated sand units.

The sandstone units included in the paralic (mixed-marine) zone could not be quantitatively compared because of the lack of resistivity data in that portion of MWX-2 log. Qualitatively, however, the entire interval correlates well across the 139-ft distance between the wells. The sandstone zone in both wells is approximately 200 ft thick, has a low gamma ray value and has no significant shale breaks. The paralic sands are distinguished from the fluvial sands by the clean and "blocky" (sharp upper/lower contacts) character of the gamma ray curve.

The fluvial zone in MWX-1 and MWX-2 can be further divided into upper, middle and lower zones based on the number of sand units and average unit thickness in the interval. Characteristics of each zone are summarized in Table 1. Quantitative correlations using the previously described method are summarized as follows:

Zone	Degree of Similarity			
	Excellent	Good	Fair	Poor
Upper Fluvial	4	3	2	2
Middle Fluvial	0	2	2	3
Lower Fluvial	4	4	2	4

MWX-1 and MWX-2 each penetrated the entire paludal section of the Mesaverde. Based on the quantitative degree of similarity of correlated sandstones, this zone is summarized as follows:

Zone	Degree of Similarity			
	Excellent	Good	Fair	Poor or No Correlation
Paludal Zone	2	7	6	9

Other Close-Paired Well Correlations. Eight other well pairs in the Rulison Field were examined and are shown on Figure 8. Well-to-well distances range from 285 feet to 10,400 feet for these well pairs. In all of these well pairs, quantitative correlations were based on resistivity and gamma ray character.

The upper marine zone maintained a high sand to shale ratio and blocky gamma ray character, similar to that observed in the MWX wells, in all the other well pairs. Even at a distance of 10,400 ft some sand units in the upper marine zone had good qualitative correlations.

Rulison Field Correlation Summary. The correlation results in each of the subdivided fluvial zones is summarized in Table 1. Shown are the well pairs, the well spacing, the percent of correlative sand units, and the average thickness. It can be readily observed from this summary that as well spacing increases, percent of qualitatively correlated sand units decreases.

Correlations in the paludal zone, except for the MWX-1 and MWX-2 wells, were not possible as few other Rulison wells examined penetrated this zone.

Rio Blanco Unit Correlation Analyses

The Rio Blanco Unit is located 30 miles northwest of the Rulison Field in Rio Blanco County, Colorado. Within the study area, four closely-spaced wells on an approximate north-south orientation were chosen for correlation. They were No. 1 Government Fawn Creek, RB-E-01, RBU No. 4 and RB-MHF-3. As shown in Figure 11, well-to-well spacing ranges from 651 to 3,995 ft. The wells penetrated from 831 to 1,700 ft of Mesaverde section interpreted to be equivalent to the paralic and fluvial zones.

The correlations from all four wells were placed on a composite cross section and, as a result, various combinations of well-to-well distances are available to correlate sandstone units along the line of section. Units "bracketed" between the Fawn Creek No. 1 well and the RB-MHF-3 well correlations can be assigned a maximum correlation distance equal to the distance between the wells. Other sand units which correlate "open-ended" across the section can be assigned a minimum correlation distance equal to the distance between the wells. Sand units which are "open-ended" and are evident in only one well have continuity over an unknown distance.

Correlation of significant sand units between well pairs was qualitatively based on resistivity log character (shape and value), gamma ray character where available, thickness of sand bodies, and spatial relationships between correlated units.

The zone interpreted to be paralic ranges in thickness from 50 to 80 ft and the sand percentage ranges from 88 to 100 percent. The sands appear cleaner and thicker, have sharp upper and lower contacts, have uniformly low resistivity, and correlate well across, at least, the 5,865 ft distance between wells Fawn Creek No. 1 and RB-MHF-3.

Correlations in the four-well composite cross section indicate that there are 44 significant sand bodies in the drilled portion of the fluvial zone. Of these 44 units, 16 were continuous across an unknown distance (open-end sand body evident in only one well). The continuity of the remaining 28 units is continuous across a distance less than 4,950 ft.

CONCLUSIONS

Close-well correlation of the uppermost Mesaverde Group sands indicates that the section in both the Rulison Field and Rio Blanco Unit has similar log character (thick, clean sandstone), has a characteristically high (greater than 75 percent) sand percentage, and is continuous between wells spaced at 10,400 ft. These observations lead to the conclusion that this section, overall, maintains a blanket-like geometry on a local and regional scale that is characteristic of shoreline sand aprons. This conclusion supports the interpretation made by Lorenz[1] of outcrop studies at Rifle Gap that the uppermost 300 ft of the Mesaverde Group are paralic (mixed-marine)/shoreline sandstones. Although the section is approximately 200 ft thick in the Rulison Field area and approximately 80 ft thick in the Rio Blanco study area, the difference can possibly be accounted for by an erosional unconformity between the Mesaverde and Wasatch Formations.[11]

In the Rulison Field, where the fluvial zone was divided into the upper, middle and lower zones, the following interpretations can be made based on these close-well correlation results.

Upper Fluvial Zone. Relatively higher sand percentages and thicker sand units indicate that this interval may have had longer residence times of meander systems. Therefore, sand units in this interval can be interpreted to be laterally extensive, thicker and possibly interconnected. Based on the extrapolation of the data points in Figure 12, 50 percent of the sand units in this interval with a thickness range of 20 to 30+ ft should be continuous to approximately 3,250 ft.

Middle Fluvial Zone. Relatively thinner and fewer sand units in this interval indicate that although sedimentation patterns are similar to the upper zone, residence times of the meander systems were likely to be much less or there was a decreased sediment supply. Therefore, discontinuity of sand units may dominate and based on extrapolation of data points in Figure 13, 50 percent of the sand units encountered in this interval with a thickness range of 20 to 30+ ft should be continuous to approximately 2,700 ft.

Lower Fluvial Zone. Correlation of sandstone units in this interval appears similar to the upper fluvial zone. Based on the extrapolation of data points in Figure 14, 50 percent of the sandstone units with a thickness range of 20 to 30+ ft should be continuous to approximately 3,160 ft. Compared to the upper fluvial zone, this decreased correlation distance may reflect lower depositional energy conditions in an environment transitional from paludal to fluvial.

All Zones. Close well correlations of the entire fluvial Mesaverde section are summarized in Figure 15. The combined results of the Rulison and Rio Blanco close-well correlation data points indicate that approximately 75 percent of the sand units with average thicknesses from 20 to 30+ ft are correlative across 1,700 ft. Based on a linearly regressive best fit line of the data points, 50 percent of the sand units with thicknesses from 20 to 30+ should be correlative across the distance of 3,400 ft and no units should correlate further than 6,800 ft. No obvious correlation of sand body thickness to correlatable distance was apparent in this study as thicker sandstone units did not consistently correlate over longer distances. Therefore, it is not possible to predict which sand units in the 20 to 30 ft thickness range will be more or less continuous than others.

The results of this study compare with those proposed by others. Knutson[9] proposed a point-bar dimension ratio where a 25-ft thick unit would have a projected length of 4,750 ft and a width of 2,000 ft. Considering these length and width dimensions, the maximum correlatable distance would be 5,150 ft. In another study, by Hodges,[12] based on measured outcrops of the fluvial Mesaverde section (Williams Fork Formation) at Rifle Gap, the median apparent length:height ratio was 60, but ranged from less than 20 to greater than 200 (Hodges,[12] Figure 28). Thus, an average 25-ft thick unit is projected to have a median apparent length of 1,500 ft but can range from less than 500 ft to more than 5,000 ft. The correlative distance of 3,400 ft (distance at which 50 percent of the units are correlative) arrived at in this study is within limits of the projected sandstone unit dimensions in both comparison studies.

With the knowledge that there is a good chance (greater than 50 percent) that a fluvial Mesaverde sandstone unit in the 20 to 30+ ft thickness range will be continuous up to a distance of 3,400 ft, a number of potential applications are possible. These potential uses, valid in other areas if depositional conditions are similar to the Rulison Field and Rio Blanco Unit, are:

- maximization of hydraulic fracturing treatments to extend the fracture to the reservoir limits, and
- calculation of a better gas reserve estimate knowing an approximate reservoir size.

There may be certain limitations to the interpretations of the close-well correlations, however. These limitations are shown by the following examples.

- In one well pair, 17 percent of the sand units were interpreted to be correlative across 10,400 ft. The discrepancy with the predicted maximum correlation distance may illustrate the limitation that as well-to-well distances increase, qualitative correlations made by matching similar log curve shapes may actually be correlations of discontinuous sand bodies coincidentally having similar curve shapes or sand thicknesses at the same horizon. Such a situation, in outcrop, was illustrated in Figure 6.
- Those wells in the study at 139 and 285 ft show that approximately 75 percent of the fluvial zone sand units are correlatable, much less than expected. This may be a result of one wellbore penetration near the edge of a lens and the other outside of the lens. If two wells were spaced inches apart, however, it is likely that 100 percent of the lenses would correlate from well-to-well. This is the basis for intersecting the y-axis at 100 percent in Figures 12, 13, 14 and 15.
- Depositional trends and the orientation of well placements are not expected to affect the results. As was illustrated in Figure 4, random orientation of the long dimension of point-bars dominates, even though the meander belt has a definite trend. Therefore, placement of wells along the strike or dip of the meander belt should make little difference in close-well correlations.
- A statistically significant number of wells or sandstone units may not have been included in this analysis. Closely-spaced wells drilled in the future should be added to this set of data.
- Interpretation of data from the paludal zone is inconclusive due to a lack of closely-spaced wells penetrating the interval. The best data available in MWX-1 and MWX-2 indicates 63 percent of the sandstone units were correlative across 139 ft. This somewhat poorer correlation percent may indicate the sandstone units are relatively less continuous in comparison to those of the fluvial zone. Dimensions of paludal zone (Iles Formation) sandstone units have been studied by Hodges[12] at the Rifle

Gap outcrop. Based on measurements of outcrops, a median apparent length:height ratio of 60 was arrived at and based on geometric considerations extrapolated from geologically similar areas, a width:height ratio of 38 was calculated. These ratios could be applied as a first approximation of dimensions of channel fill deposits in the lower Mesaverde paludal zone.

NOMENCLATURE

V_{sh} = shale volume

ρ_B = bulk density

R_t = deep resistivity

GR = gamma ray

gm/cc = grams/cubic centimeter

ACKNOWLEDGEMENTS

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SI METRIC CONVERSION FACTORS

Ft x 3.048 = m

mile x 1.609 = Km

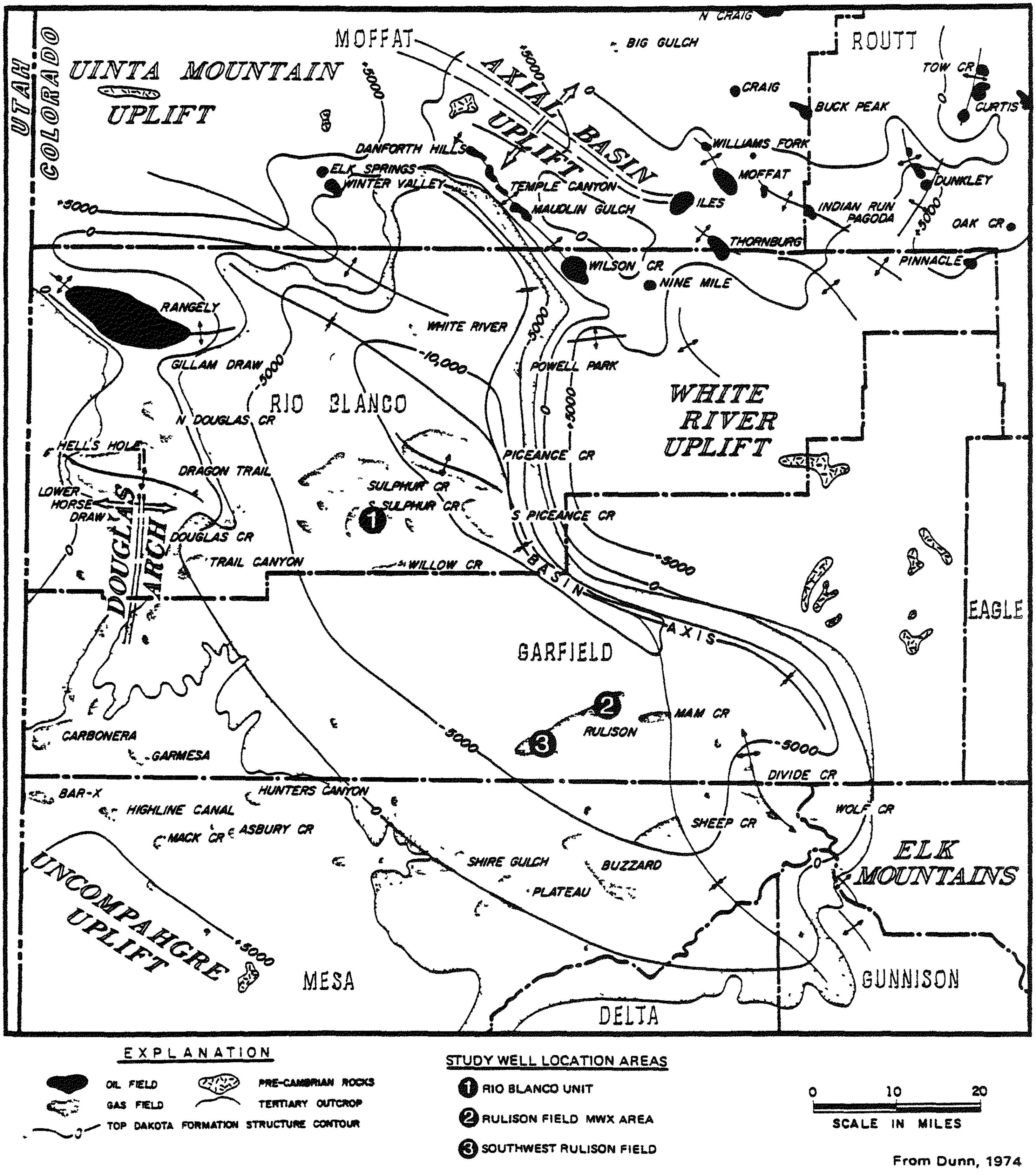
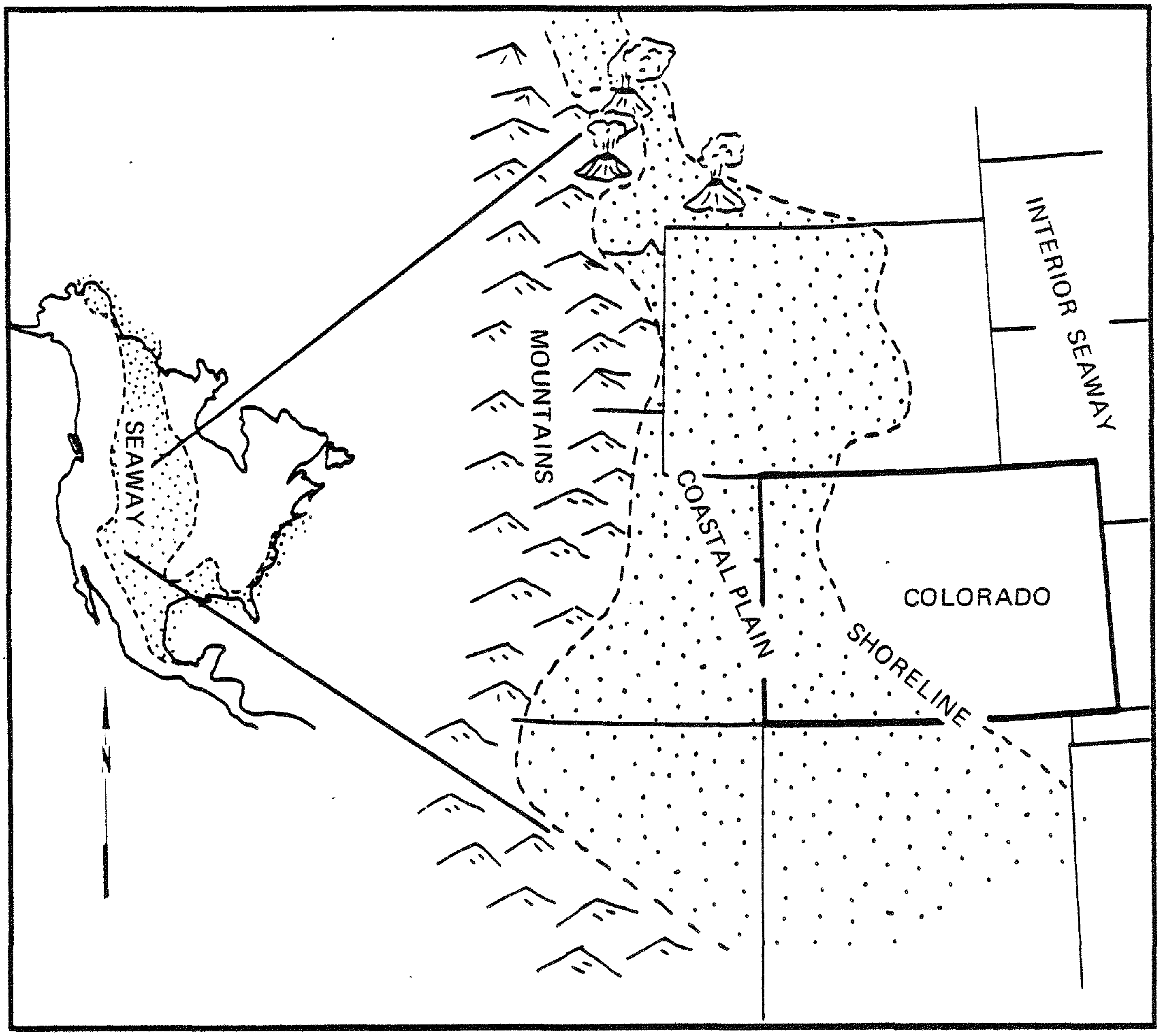
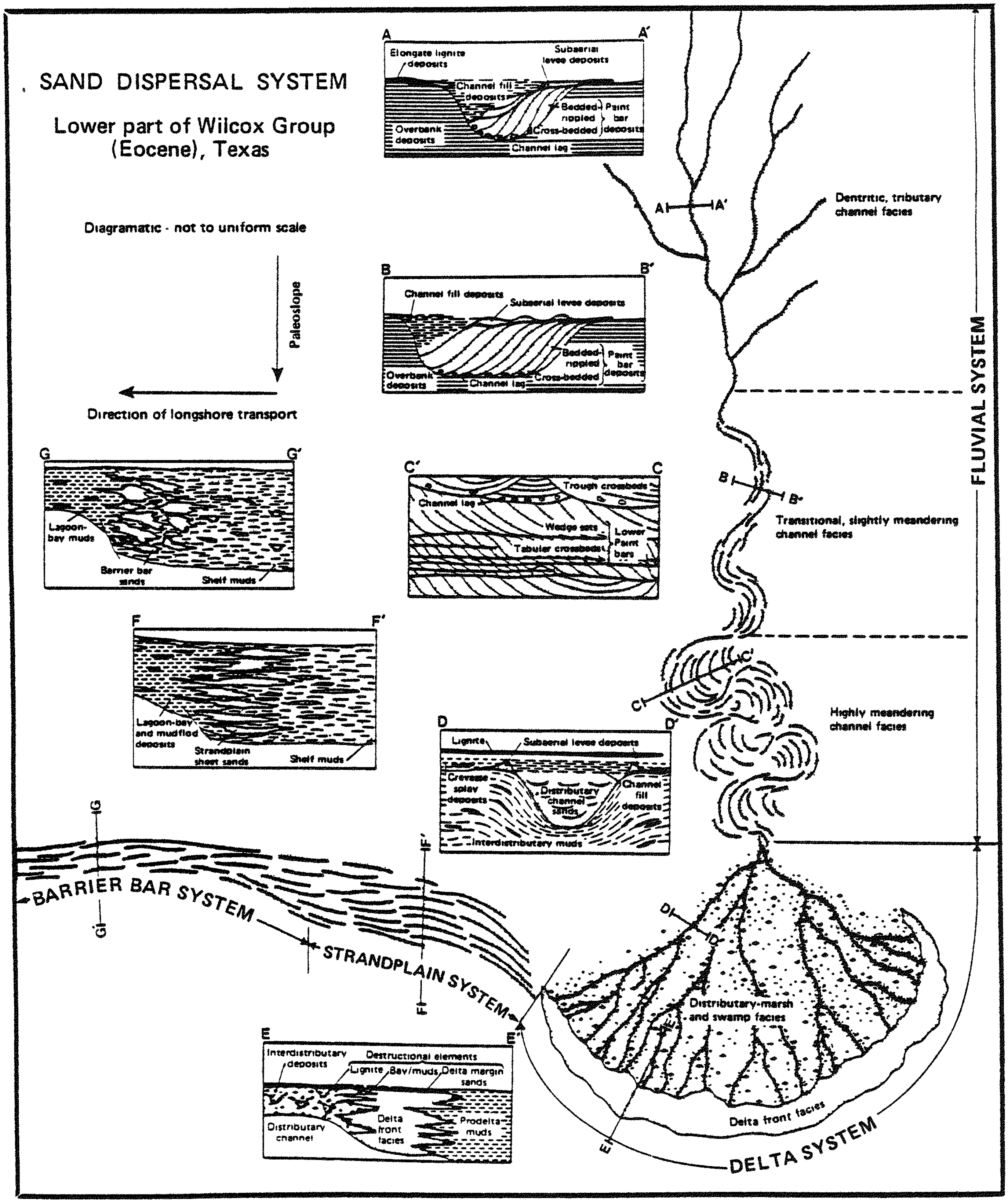


Figure 1 Oil and Gas Fields and Major Structural Elements, Piceance Basin and Contiguous Areas



From Lorenz (1982)
After Mallory et al (1972)

Figure 2 Generalized Paleogeography of the Central Rocky Mountain Region During Late Cretaceous Time



From Fisher and McGowen (1969)

Figure 3 Diagrammatic Sand-Dispersal System in Various Depositional Systems of Lower Wilcox

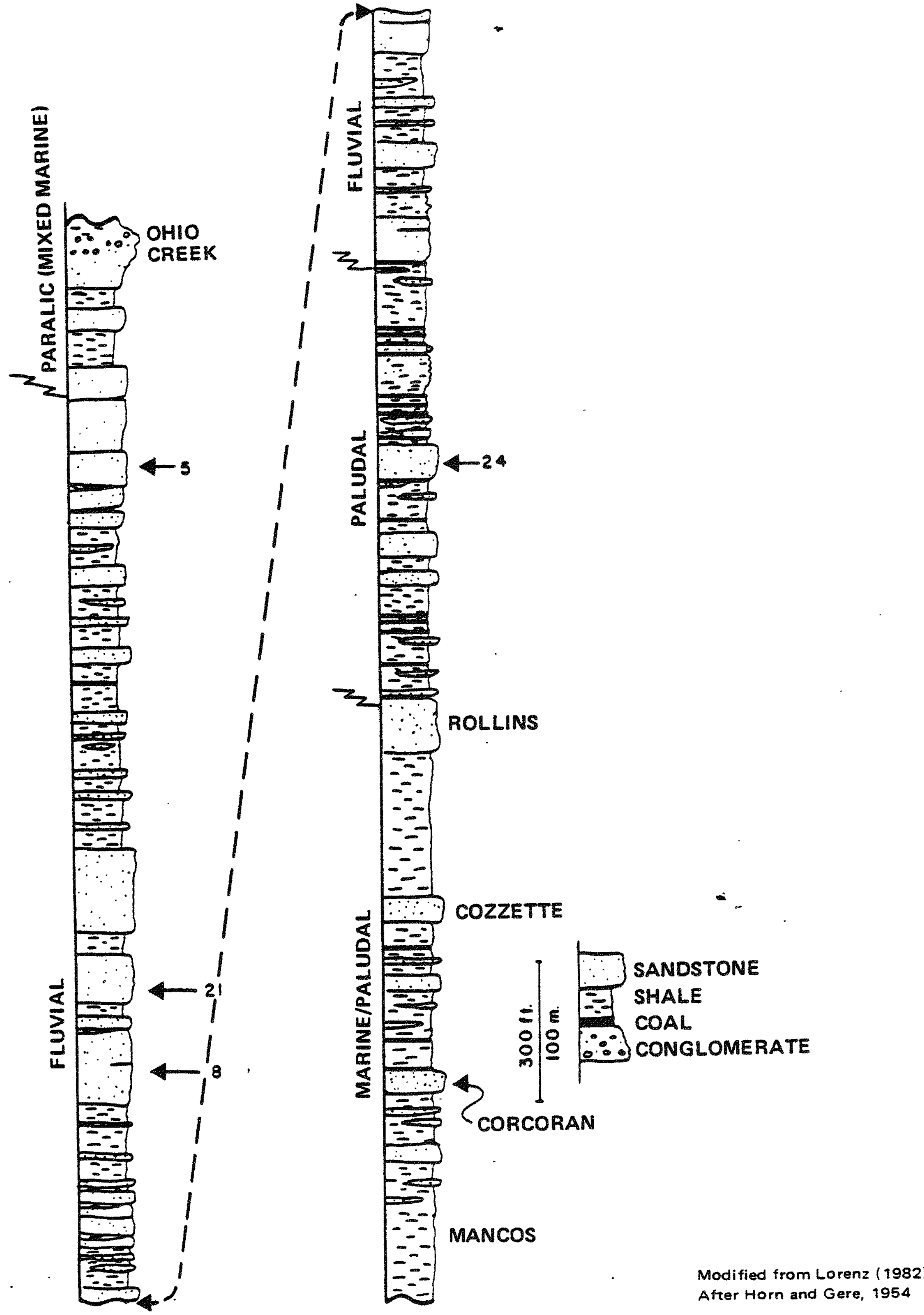
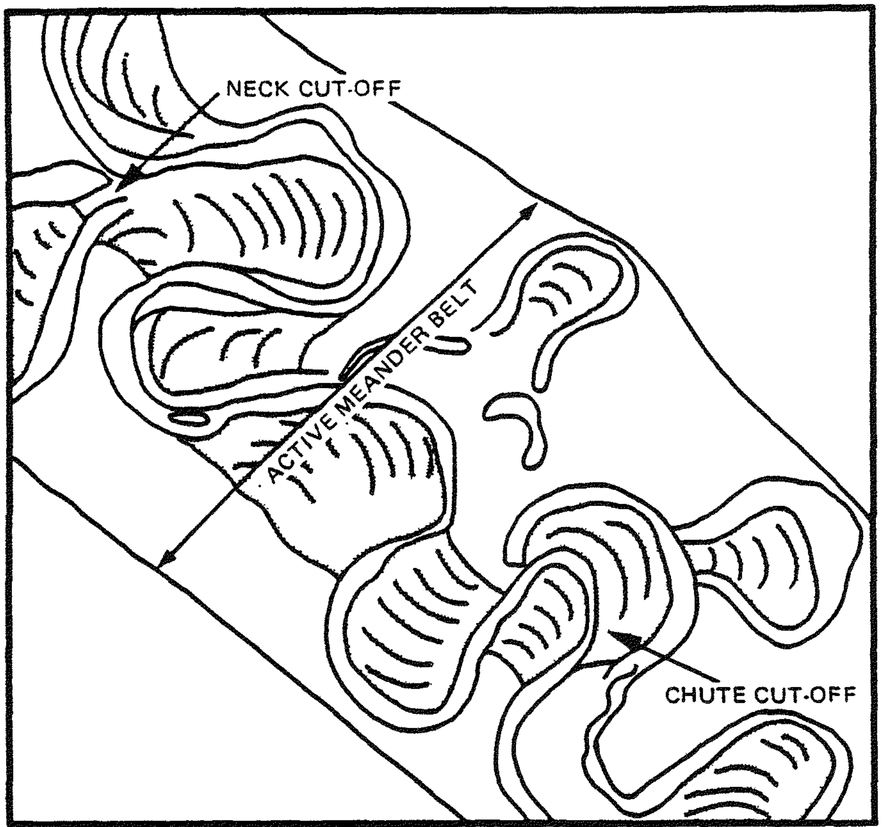
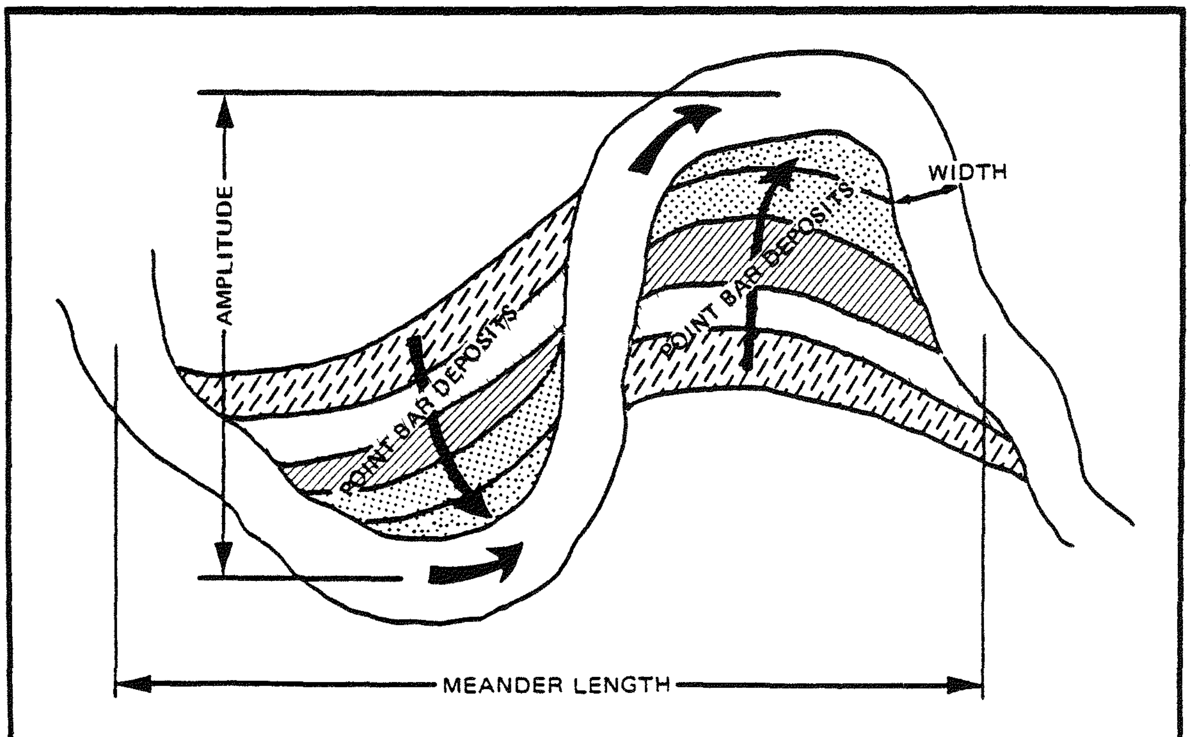


Figure 4 Measured Stratigraphic Column Through Mesaverde Rocks in Rifle Gap



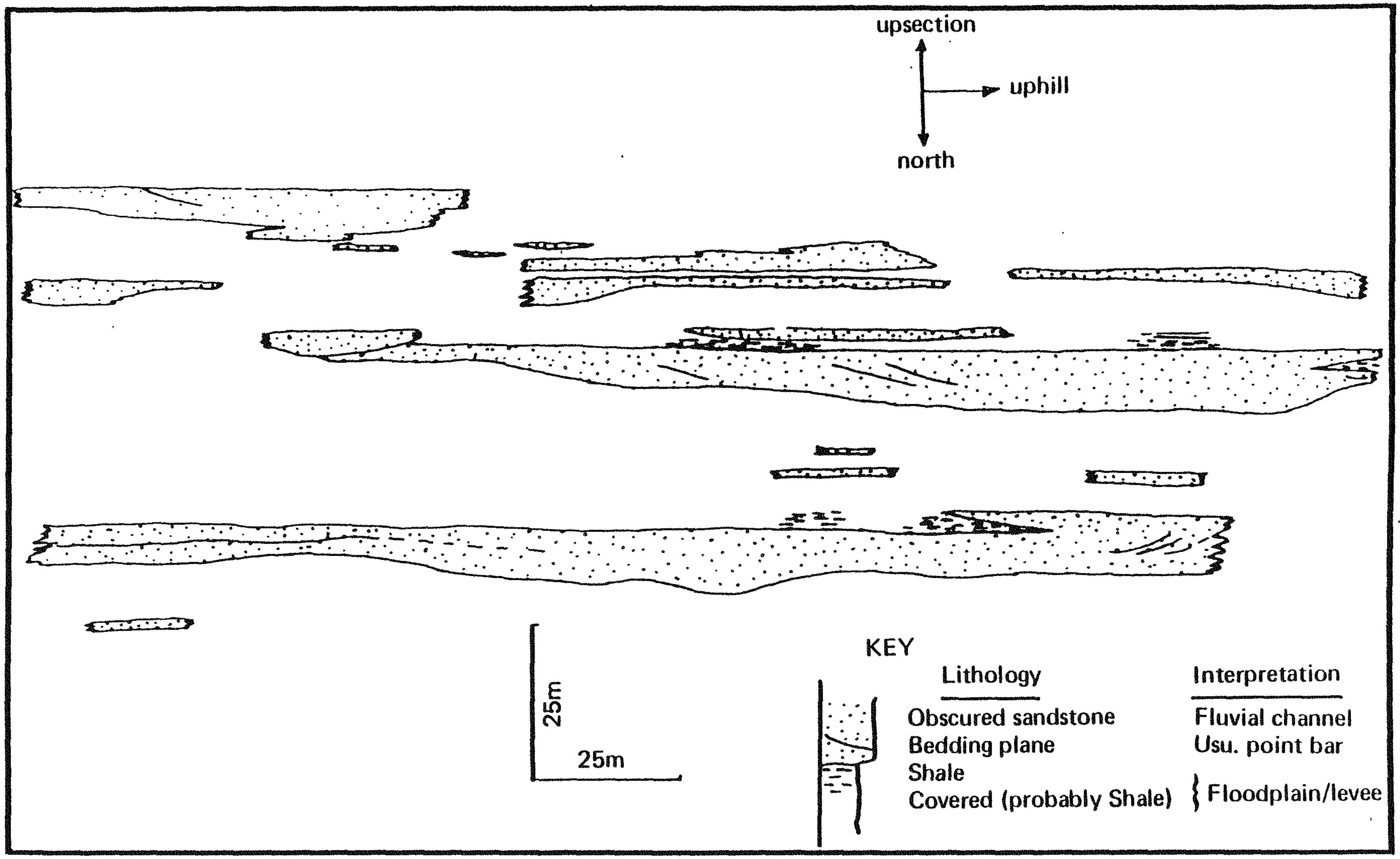
Modified from Swanson

Figure 5 *Diagrammatic Outline of Meander Patterns and Point-Bar Deposits of the Laramie River, Wyoming*



Modified from Swanson

Figure 6 *Morphology of a Meandering Stream*



From Lorenz (1982)

Figure 7 Outcrop of Lens Group in the Fluvial Mesaverde Section, West Side of Rifle Gap

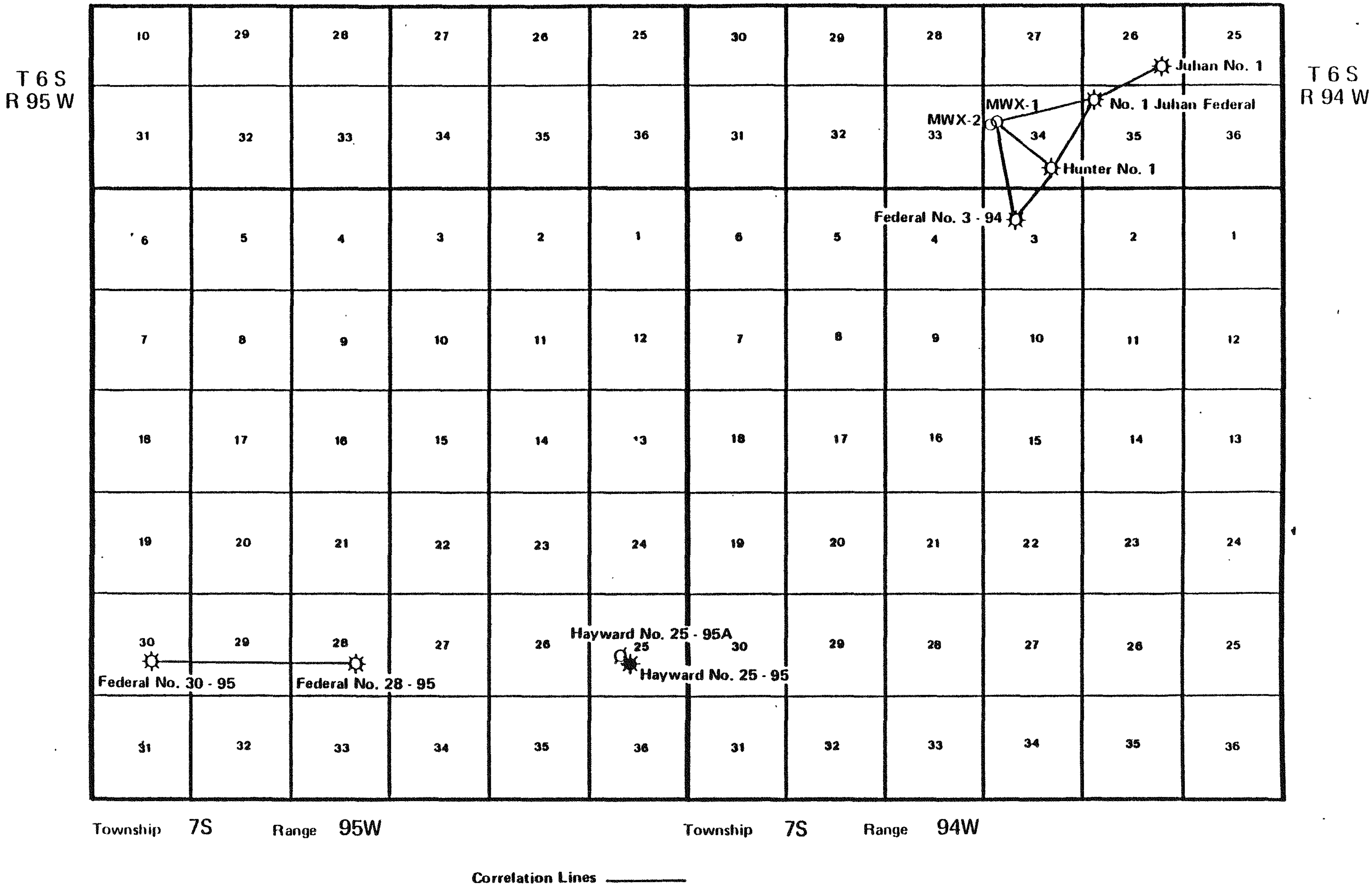


Figure 8 Rulison Field Study Well Location Map

Table 1 Characteristics of Fluvial Zone Subdivisions, Rulison Field

	Well Spacing, ft	Correlative Sand Units	Thickness in ft of all units, min-max, avg.	Interval	
UPPER FLUVIAL ZONE				**Feet**	**Well**
MWX-1 & MWX-2	135	9/11 = 81%	9 - 35, 17	4,280 - 4,950	MWX-1
Hayward 25-95 & Hayward 25-95A	285	8/10 = 80%	12 - 38, 21	6,370 - 6,910	Hayward 25-95
Federal 3-94 & Hunter No. 1	3,498	5/12 = 42%	11 - 54, 24	4,250 - 4,950	Hunter No. 1
Hunter No. 1 & No. 1 Juhan Federal	4,191	5/17 = 29%	13 - 54, 27	4,250 - 5,000	Juhan Federal
MWX-1 & Hunter No. 1	4,224	5/14 = 36%	13 - 40, 24	4,250 - 4,950	MWX-1
No. 1 Juhan Federal & Juhan No. 1	4,257	9/13 = 69%	11 - 54, 23	4,250 - 4,916	Juhan Federal
MWX-1 & Federal 3-94	4,554	6/14 = 43%	12 - 40, 24	4,278 - 4,950	MWX-1
MWX-1 & No. 1 Juhan Federal	5,412	4/16 = 25%	8 - 54, 24	4,250 - 4,950	MWX-1
Federal 30-95 & Federal 28-95	10,400	1/7 = 14%	15 - 51, 33	4,040 - 4,450	Federal 30-95
MIDDLE FLUVIAL ZONE					
MWX-1 & MWX-2	135	4/7 = 57%	6 - 24, 14	4,959 - 5,460	MWX-1
Hayward 25-95 & Hayward 25-95A	285	1/1 = 100%	10 - 10, 10	6,910 - 7,410	Hayward 25-95
Federal 3-94 & Hunter No. 1	3,498	3/15 = 20%	11 - 34, 18	4,950 - 5,450	Hunter No. 1
Hunter No. 1 & No. 1 Juhan Federal	4,191	2/10 = 20%	9 - 36, 19	4,950 - 5,450	Hunter No. 1
MWX-1 & Hunter No. 1	4,224	3/12 = 25%	10 - 34, 19	4,950 - 5,450	Hunter No. 1
No. 1 Juhan Federal & Juhan No. 1	4,257	2/9 = 22%	9 - 23, 16	4,916 - 5,460	Juhan Federal
MWX-1 & Federal 3-94	4,554	1/12 = 8%	11 - 32, 18	4,850 - 5,350	MWX-1
MWX-1 & No. 1 Juhan Federal	5,412	2/8 = 25%	9 - 36, 19	4,950 - 5,450	MWX-1
Federal 30-95 & Federal 28-95	10,400	0/4 = 0%	14 - 32, 21	4,450 - 4,790	Federal 30-95

Continued

Table 1 Continued

	Well Spacing, ft	Correlative Sand Units	Thickness in ft of all units, min-max, avg.	Interval	
LOWER FLUVIAL ZONE				**Feet**	**Well**
MWX-1 & MWX-2	135	10/14 = 71%	5 - 37, 19	5,460 - 6,595	MWX-1
Hayward 25-95 & Hayward 25-95A (7,410 - 8,420 ft)	285	12/16 = 75%	10 - 40, 28	7,410 - 8,420*	Hayward 25-95
Federal 3-94 & Hunter No. 1	3,498	4/13 = 31%	9 - 58, 27	5,450 - 6,020*	Hunter No. 1
Hunter No. 1 & No. 1 Juhan Federal	4,191	6/19 = 32%	8 - 52, 26	5,450 - 6,570	Hunter No. 1
MWX-1 & Hunter No. 1	4,224	5/18 = 28%	8 - 60, 26	5,450 - 6,570	Hunter No. 1
No. 1 Juhan Federal & Juhan No. 1	4,257	7/20 = 35%	8 - 50, 23	5,400 - 6,375	Juhan Federal
MWX-1 & Federal 3-94	4,554	4/9 = 44%	8 - 50, 20	5,450 - 6,100*	MWX-1
MWX-1 & No. 1 Juhan Federal	5,412	5/21 = 23%	8 - 34, 20	5,450 - 6,560	MWX-1
Federal 30-95 & Federal 28-95	10,400	5/24 = 21%	10 - 66, 22	4,790 - 6,110*	Federal 30-95

* Section not completely penetrated

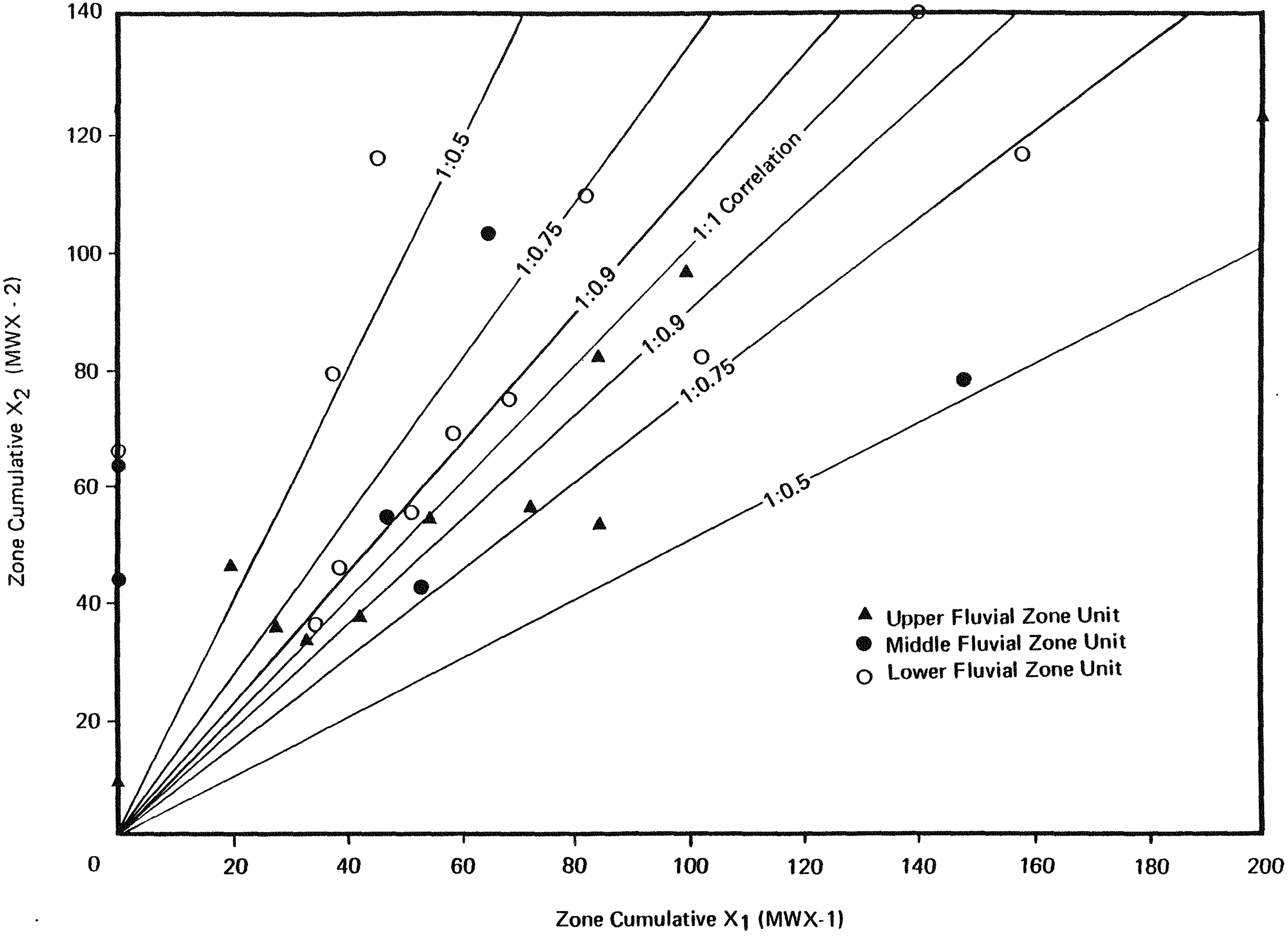


Figure 9 Degree of Similarity of Fluvial Zone Sandstone Units, MWX-1 and MWX-2

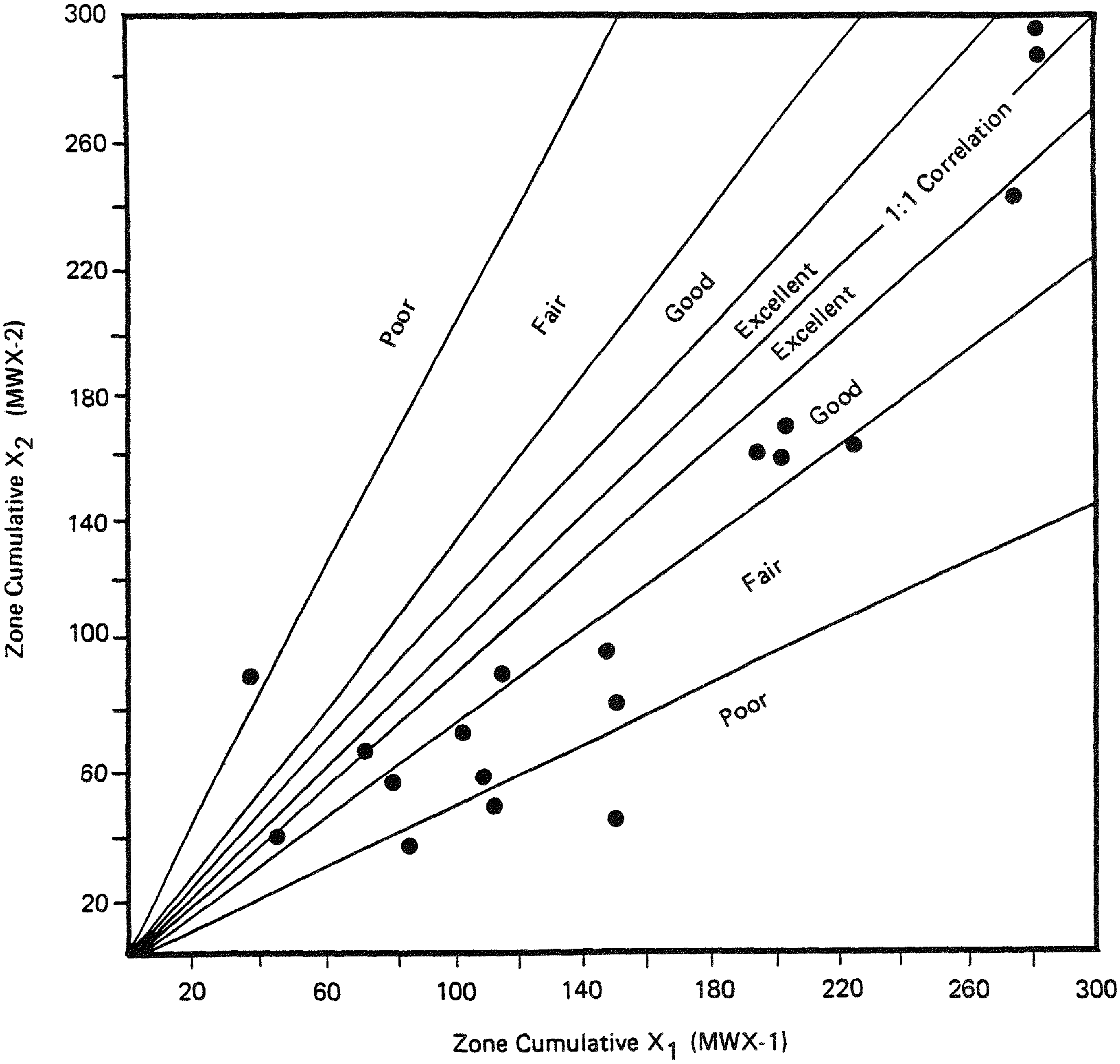


Figure 10 *Degree of Similarity of Paludal Zone Sandstone Units, MWX-1 and MWX-2*

Township 3S, Range 98W, Rio Blanco County, Colorado

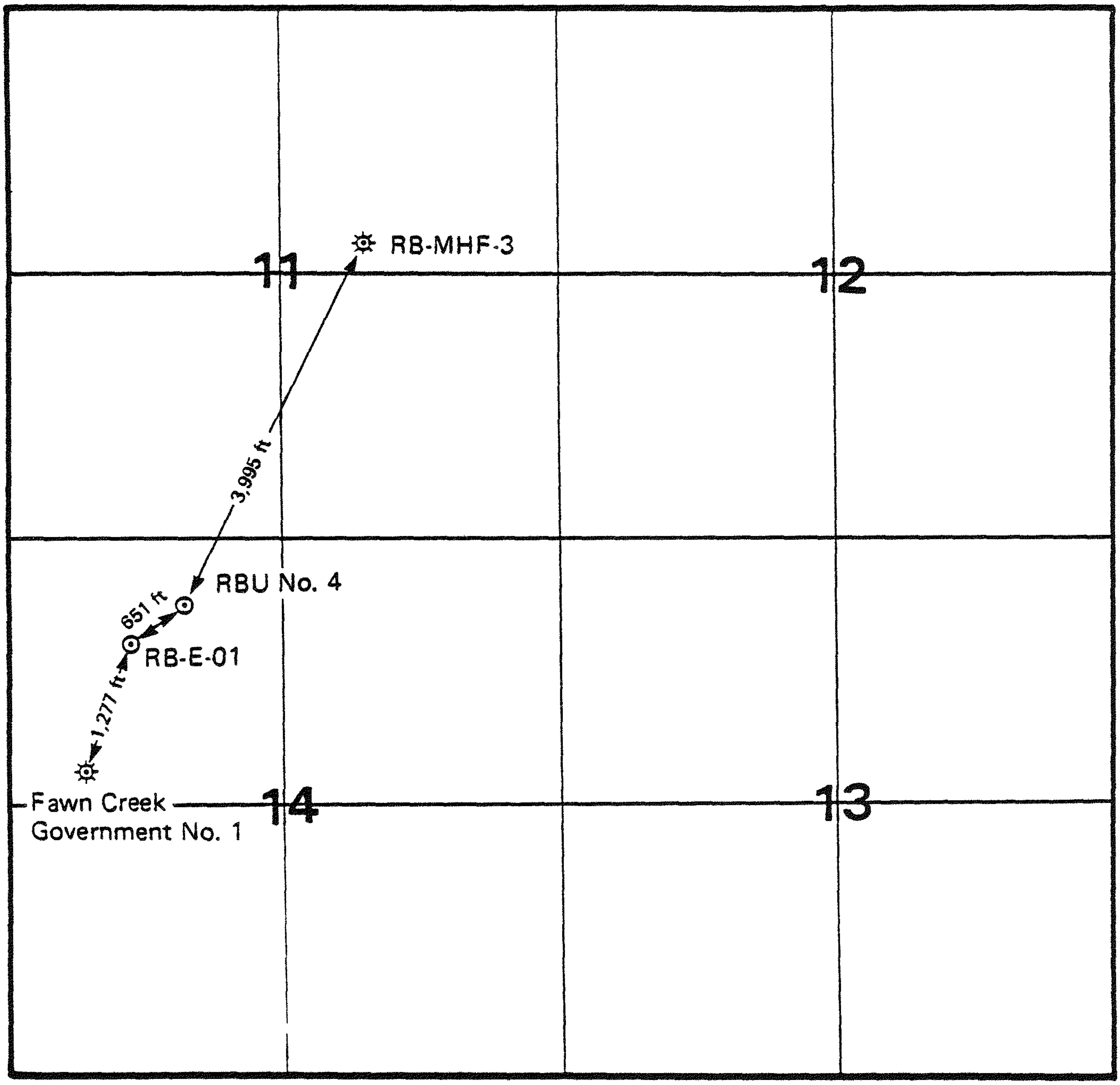


Figure 11 *Rio Blanco Unit Study Well Location Map*

Table 2 Continuity of Sandstone Units in the Rio Blanco Unit

	CORRELATED DISTANCE				
	FC No. 1 to RB-MHF-3 5,865 ft	RB-E-01 to RB-MHF-3 4,604 ft	RBU No. 4 to RB-MHF-3 3,995 ft	FC No. 1 to RBU No. 4 1,940 ft	FC No. 1 to RB-E-01 1,277 ft
OPEN-ENDED CORRELATIONS (Apparent Minimum Continuity)					
Correlative Sandstone Units	9/28 = 32%	5/28 = 19%	1/28 = 4%	4/28 = 14%	3/28 = 11%
Unit Thickness, min - max, avg.	15 - 40 ft, 24 ft	16 - 35 ft, 23 ft	24 ft	26 - 36 ft, 29 ft	27 - 40 ft, 34 ft
BRACKETED CORRELATIONS (Apparent Maximum Continuity)					
Correlative Sandstone Units	1/28 = 4%* 1/28 = 4%**	3/28 = 11%***	– – –	1/28 = 4%****	– – –
Unit Thickness, min - max, avg.	21 - 38 ft, 30 ft	8 - 12 ft, 10 ft	– – –	– – –	– – –
UNKNOWN CONTINUITY:					
16 Sandstone Units					

* Correlation distance may be as much as 5,865 ft and is at least 651 ft

** Correlation distance unknown but is less than 5,865 ft

*** Correlation distance unknown but is less than 4,604 ft

**** Correlation distance unknown but is less than 1,940 ft

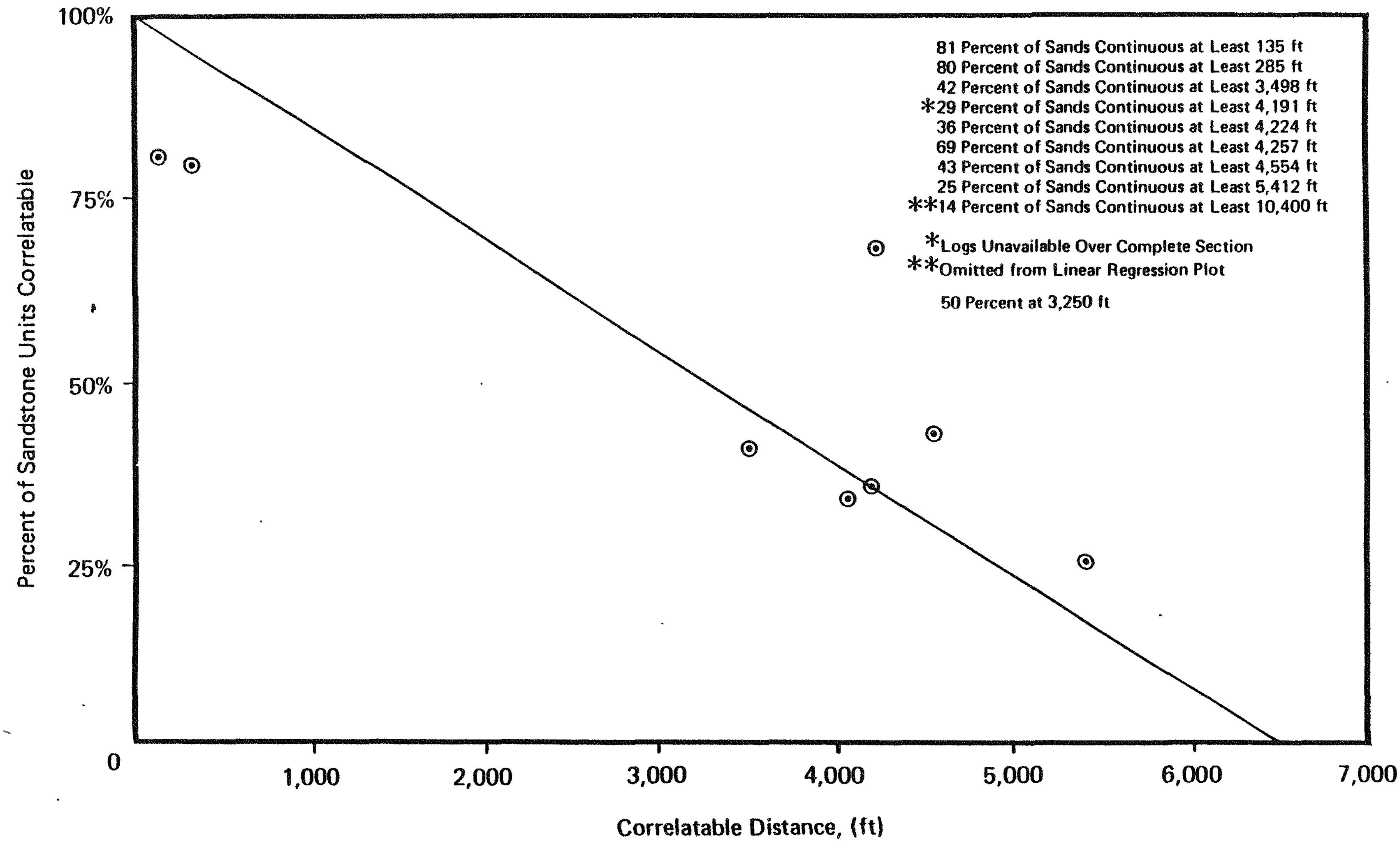


Figure 12 Correlatable Distance of Upper Fluvial Zone Sandstone Units, Rulison Field Study Wells

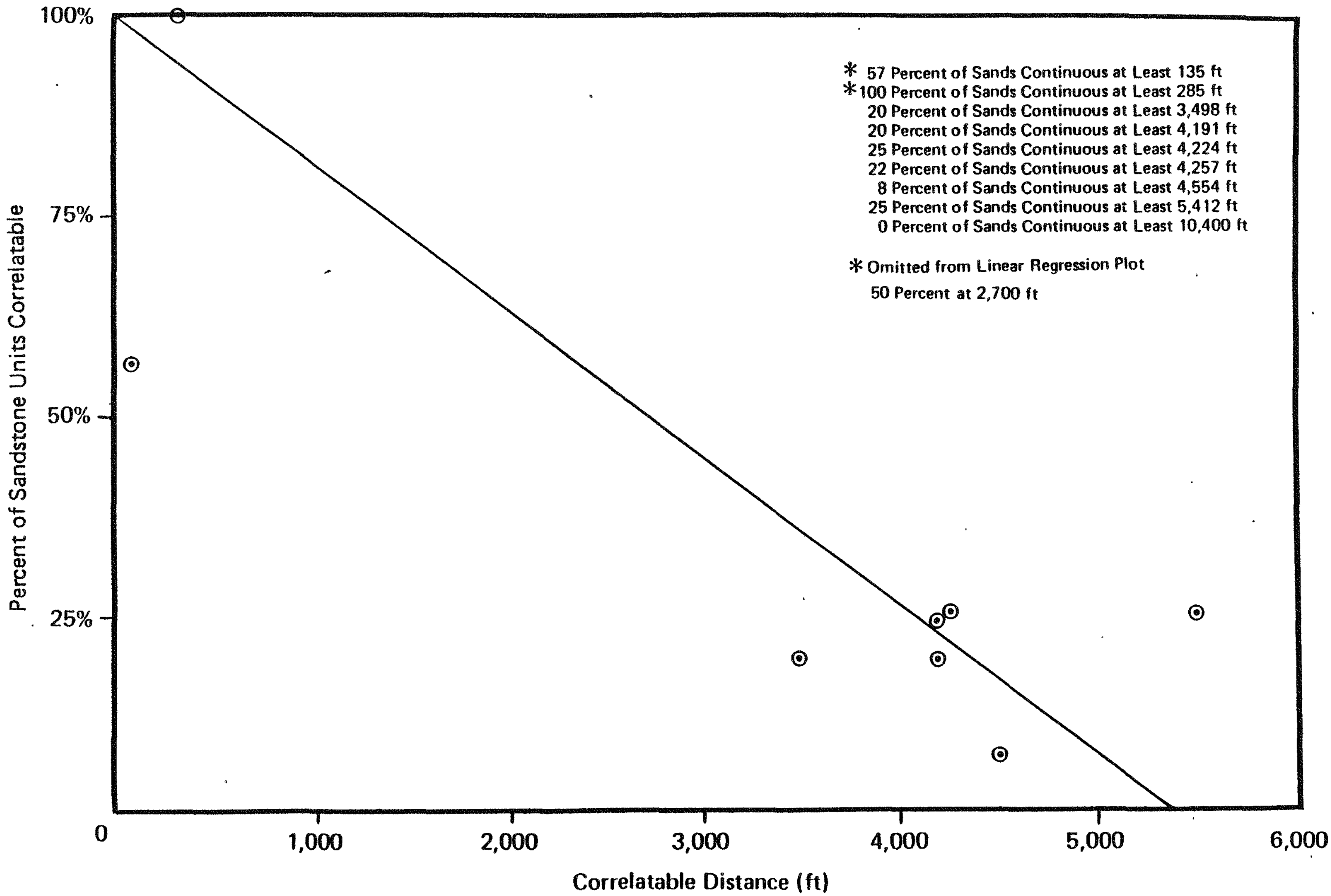


Figure 13 Correlatable Distance of Middle Fluvial Zone, Rulison Field Study Wells

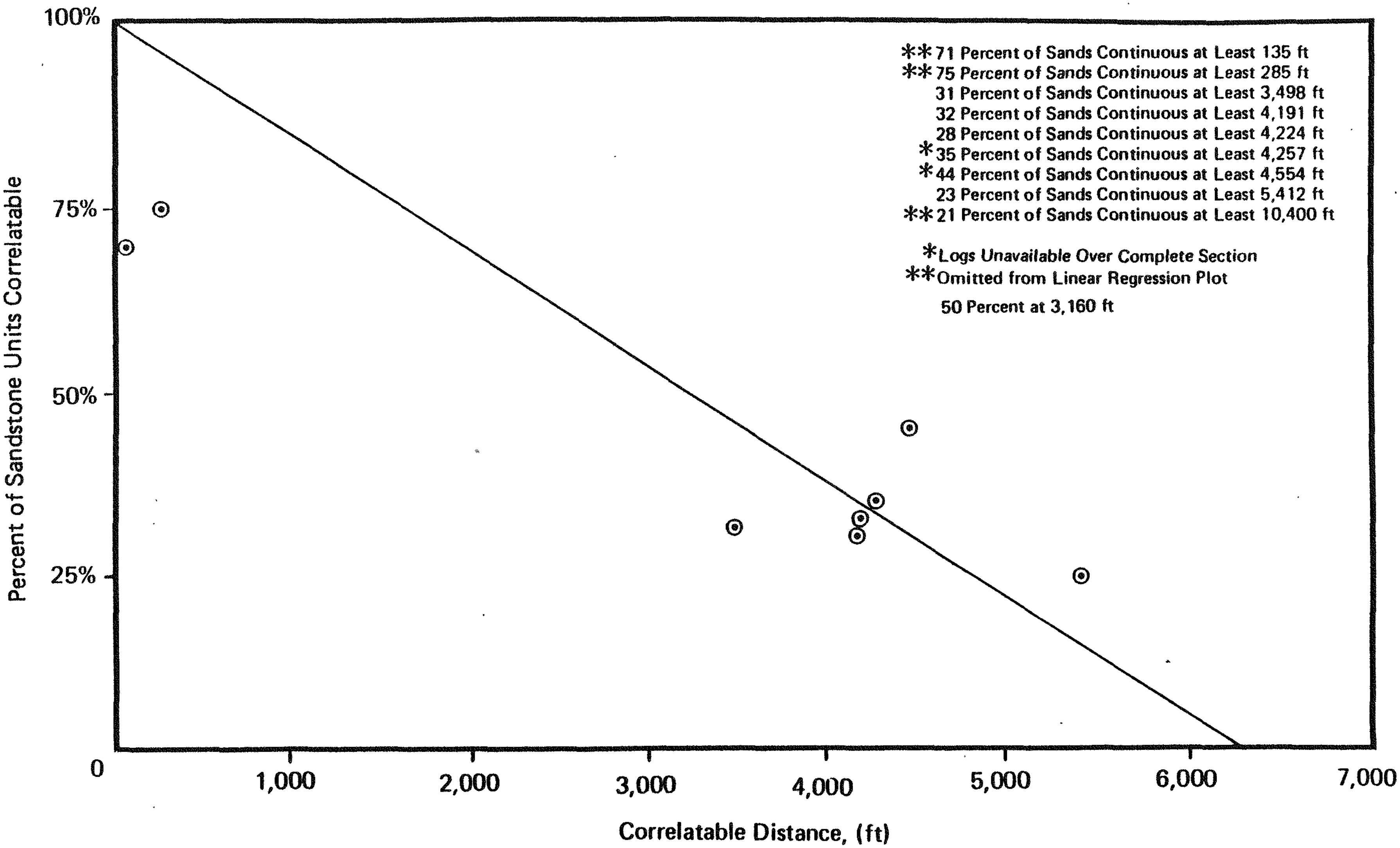


Figure 14 Correlatable Distance of Lower Fluvial Zone, Rulison Field Study Wells

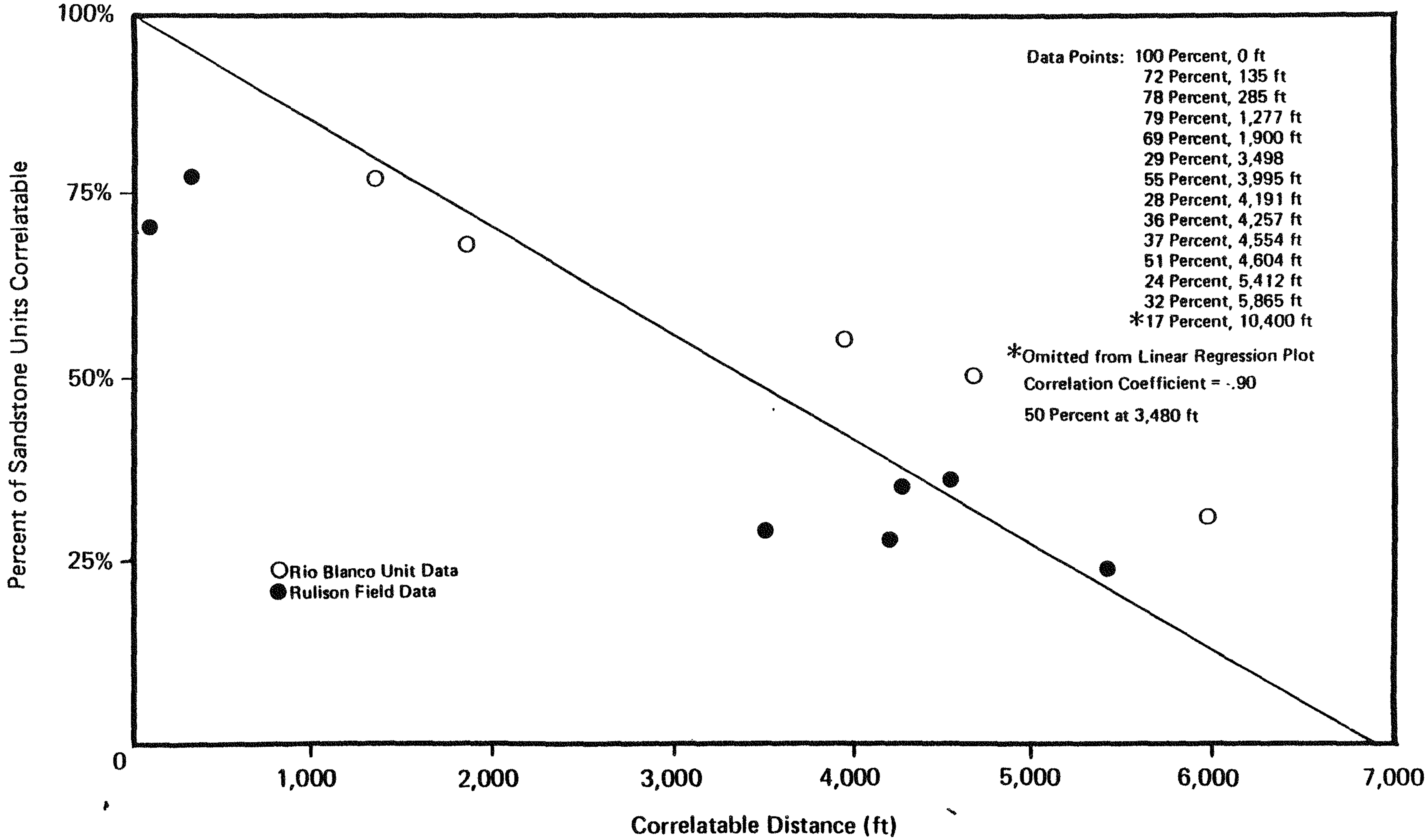


Figure 15 *Correlatable Distance of all Fluvial Sandstone Units, Rulison and Rio Blanco Field Study Wells*