The Permian Basin:
Providing Energy For America

West Texas Geological Society

Fall Symposium
October 28-29, 1999

Samson Exhibit 7
NMOCD Case Nos. 13492/13493
Submitted 8/10/06

Publication 99-106

D. T. Grace and G. D. Hinterlong
Editors

"The Permian Basin: Providing Energy For America", D. T. Grace, G. D. Hinterlong, eds.,
West Texas Geological Society Publ. # 99-106

Significance of Intraformational Unconformities in the Morrow Formation of the Permian Basin

Louis J. Mazzullo, Certified Petroleum Geologist, Albuquerque, New Mexico

ABSTRACT

The tectonic history of the Morrow Formation in the Permian Basin involved numerous syngenetic and post-depositional uplift and exposure events which locally profoundly modified its siliciclastic reservoir section. These multiple events created numerous internal stratigraphic truncations or discontinuities. Consequently, stratigraphic correlations of pay sandstones and reservoir trends in the Morrow are often difficult, even between closely-spaced wells. Intraformational unconformities or re-activation surfaces are easily missed with conventional mapping and may be very important when tracing a sandstone reservoir across a field area or in regional reservoir trend analysis. Presumptions made regarding depositional environments and reservoir trends based on log correlations alone can be misleading, and can result in either missed opportunities or dry holes.

INTRODUCTION

Natural gas reservoirs of the Lower Pennsylvanian Morrow Formation are once again in the spotlight as one of the hottest plays in the Permian Basin because of the recent drop in oil prices. Renewed interest in the play has recently resulted in an acceleration of exploration and infill drilling of Morrow sandstone targets in Eddy, Lea and Chaves Counties, New Mexico, and in the Delaware Basin of far west Texas (Figure 1). The Morrow, as with other deep gas plays in the same region, has always been an attractive target in times like this because of its potential for substantial gas reserves, but finding good Morrow wells has often been elusive. Diagenetic factors affect reservoir performance in the Morrow and have been discussed elsewhere (Mazzullo, 1999a; Mazzullo and Mazzullo, 1984; 1985). The purpose of this geologic note is to show how the geologic development of the Morrow section was more complex than previously thought, and how the tectonic development of the formation affected reservoir trends and continuity. An understanding of these mechanisms is fundamental to the success of any exploration or exploitation program for these reservoirs.

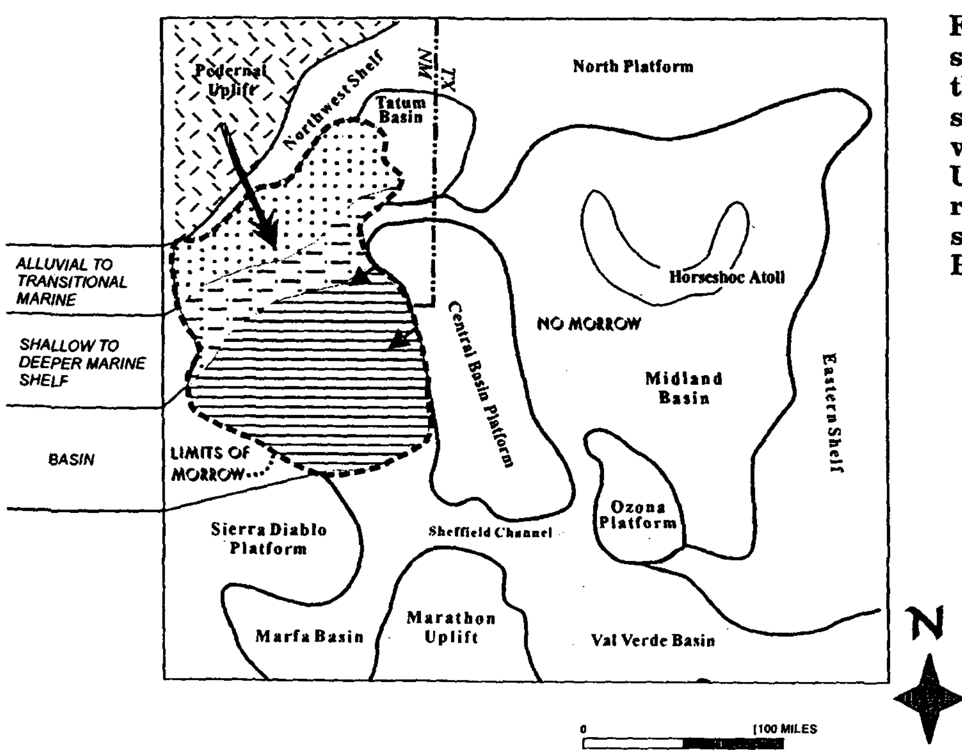


Figure 1. Location of the subsurface Morrow Formation in the Permian Basin. The major source for Morrow sediments was the ancestral Pedernal Uplift (large arrow). Small arrows denote limited source of sediments from the Central Basin Platform.

GEOLOGIC DEVELOPMENT

General

The Morrow Formation in southeastern New Mexico and west Texas produces from sandstone reservoirs that were deposited in environments ranging from fluvial through and including deeper water marine (Mazzullo and Mazzullo, 1985; Mazzullo, 1999a). The general patterns of major facies tracts in the Morrow reflect basinward (generally north to south) transitions from alluvial to deep water sedimentation along any given time line (Figure 1). The developmental history of the Morrow also involved numerous local to regional syngenetic and early post-depositional tectonic uplifts and glacio-eustatic exposure events that overprinted depositional facies. These modifications to the section, if not recognized, could create problems in correlating pay sands and tracing reservoir trends. It is not always obvious from subsurface mapping to what extent these factors affected the section in any given area.

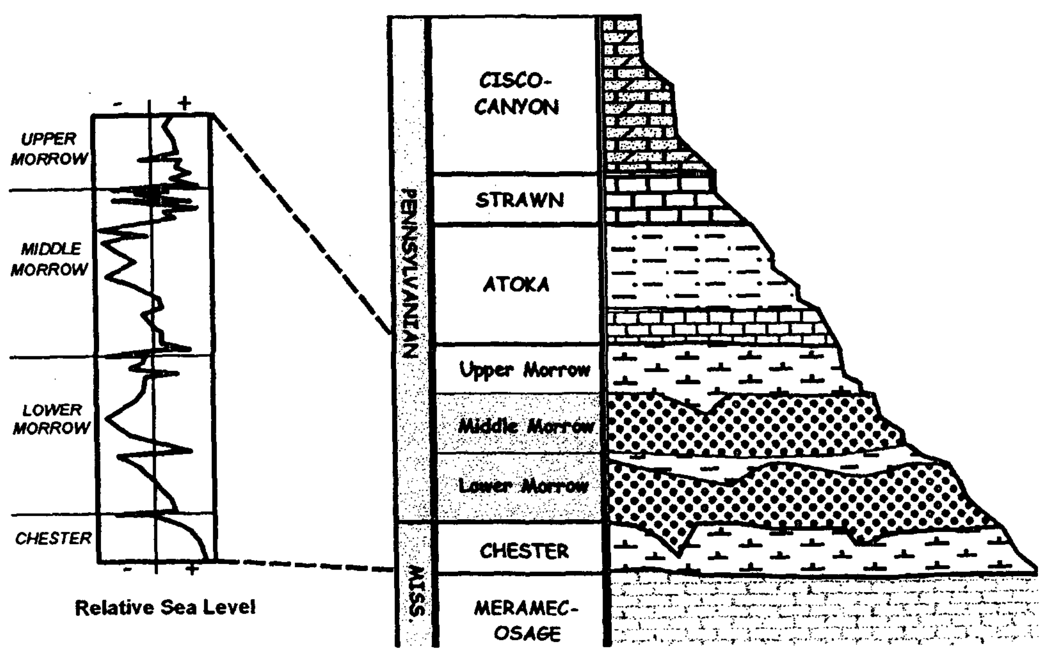
The Morrow Formation in southeastern New Mexico has been subdivided by many workers into informal lower, middle (both siliciclastic-rich) and upper (carbonate-rich) units (Figure 2), separated by what are assumed to be regional transgressive shale markers. Most of the significant natural gas reserves from the Morrow come out of sandstones in the lower and middle units, which together form the so-called "Morrow clastics" that are referred to in this paper. For the most part, the division between the lower and middle units holds up across large mapping areas, and is marked by a major highstand event followed by a drop in sea level in earliest middle Morrow time (Mazzullo, 1999a). The top of the middle Morrow unit, however, is not as easy to correlate and is often ambiguous, as are other shale markers that occur throughout the clastics section. These other shale units are also used by many workers as markers to correlate wells across fields or over larger mapping areas.

Paleozoic Tectonic History

The geologic record of the Permian Basin includes several major high-order Paleozoic tectonic episodes that have always been assumed to be the major events that shaped the basin outlines and structures. But a number of lower-order, episodic events were also important to the development and/or preservation of reservoirs, particularly throughout the Lower Pennsylvanian. Figure 3 is a schematic diagram that shows the relative magnitudes of tectonic events that were important to development of the Permian Basin. Tectonically influenced lithologic development and sporadic moderate-duration exposure events have been documented in Ordovician, Silurian, and Devonian carbonates (e.g., Holtz and Kerans, 1992; Troschinetz, 1992; Mazzullo, 1990), where they had profound influences on reservoir preservation and porosity development.

A major tectonic event occurred at the end of the Mississippian (Wright, 1979) at which time the outlines of the major features of the present-day Permian Basin began to take shape. The Central Basin Platform, for example, was a low-relief feature at this time. In some places, the initial structuring event was followed by large-scale tilting and erosion of part of the Upper to Lower Mississippian section (e.g., Mazzullo, 1999b). The next high-order basin-shaping event occurred in the Late Atoka, prior to deposition of the Strawn carbonate. Significant lower-order episodic tectonism and erosion, however, occurred throughout the Morrow and into the Early Atoka, culminating locally with

Figure 2. The major gas reservoirs in the Morrow are in sandstones of the lower and middle units. Depositional environments shifted laterally across a low-gradient shelf through time in response to repeated glacio-eustatic sea level changes. During low stands, exposure reactivated parts of the section, and concurrent uplifts contributed to localized truncation of reservoir sands (after Mazzullo, 1999a).



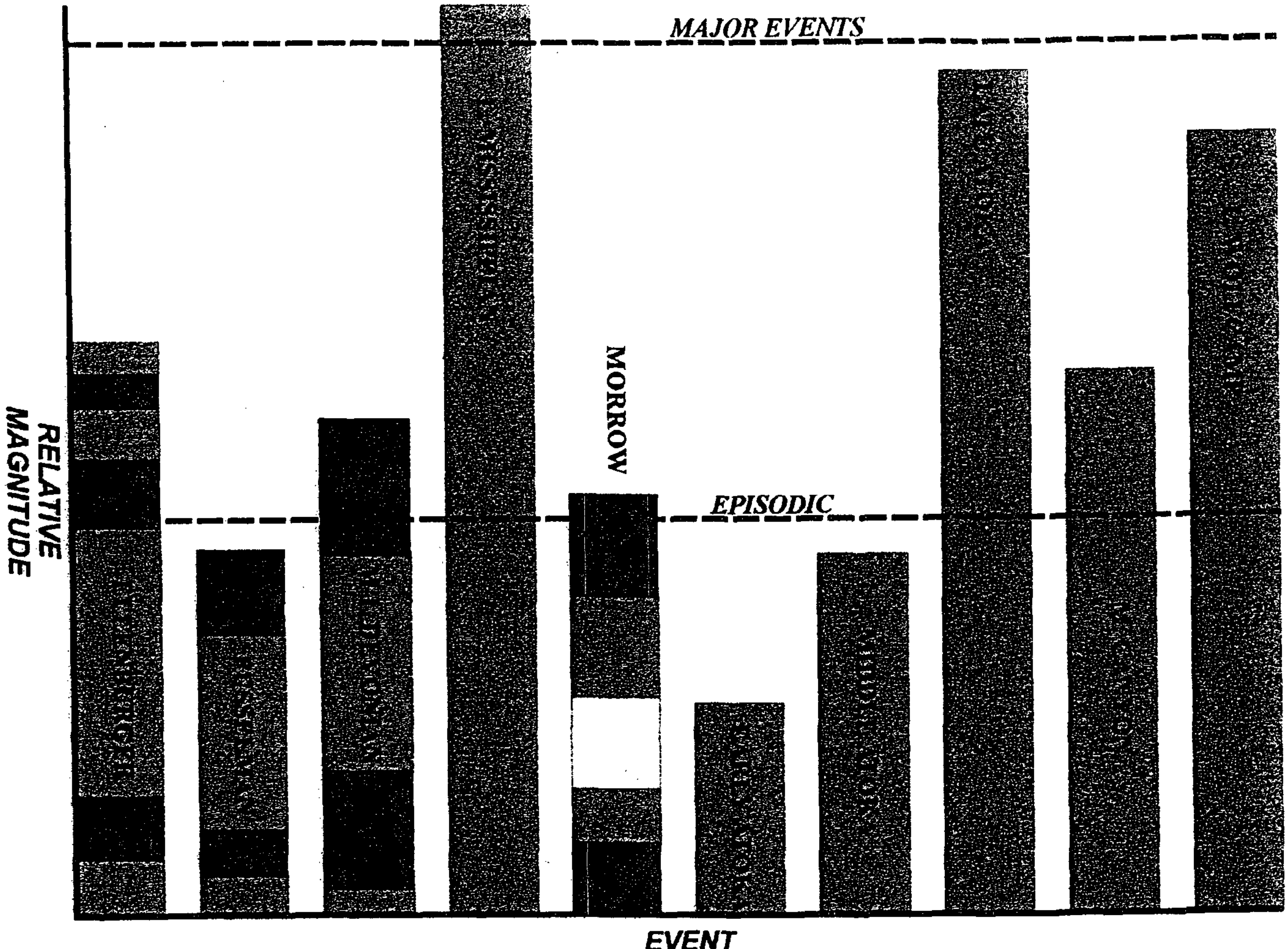


Figure 3. Schematic diagram showing relative intensities of Paleozoic tectonic events in the Permian Basin of southeastern New Mexico.

a significant tectonic uplift and exposure event in Middle Atokan time (Mazzullo, 1999b). As with earlier Paleozoic carbonates, these events influenced continuity or preservation of sandstone reservoirs throughout the Lower Pennsylvanian section.

Morrow Tectonic/Sedimentological Development

In the Permian Basin of southeastern New Mexico, geologic models of the Morrow often assume that its deposition occurred during a time of relative tectonic quiescence. The model often used assumes that prior to the Morrowan, the Upper Mississippian was subjected to a prolonged period of exposure and widespread peneplanation that provided a broad, sloping alluvial plain on which Morrow sediments were deposited, especially in areas of Eddy County where large, deep structures are not prevalent. On the contrary, the Lower Pennsylvanian in the area of present-day southeastern New Mexico was a time of relative tectonic and glacio-eustatic instability, as previously stated. The primary direct influence on Morrow sedimentation was the emergence of the ancestral Pedernal Uplift to the northwest, which supplied most of the detritus that makes up the Morrow clastics (Figure 1). The low-relief Central Basin Platform at the time provided minor amounts of sediments locally, but its continued uplift had more of an effect on post-depositional modifications to existing sediment packages in the Morrow clastics rather than as a source of sediments.

Tectonic uplifts during Morrow deposition have not been universally recognized outside of the region marginal to the Central Basin Platform (Figure 1). In that region, the Morrow was completely removed in places by early post-depositional and Atokan uplift and erosion (Mazzullo, 1999b). Outside of that region, however, tectonic uplifts coupled with glacio-eustatic sea level lowstands resulted in areas where parts of the Morrow clastic section were eroded off at different times during and after its deposition. In those areas, the Morrow section was subjected to more subtle changes that resulted from a combination of exposure during lowstands of sea level, recurrent movement along deeper faults or anticlines, and non-deposition on pre-ex-

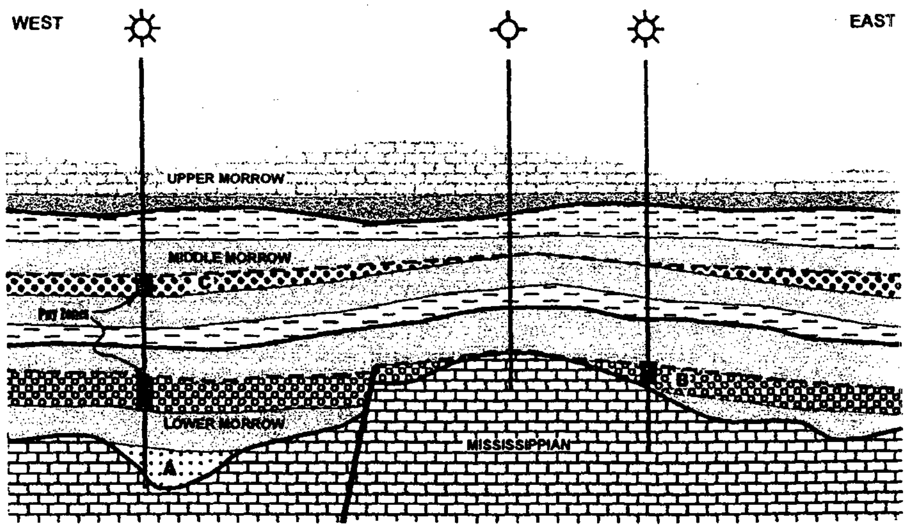


Figure 4. Types of syngenetic and post-depositional features observed in the Morrow in an area of Eddy County. Fluvial sandstone "A" is incised into the underlying eroded Mississippian surface but is absent on Mississippian highs. Unit "B", originally a continuous barrier bar sand across the area, was locally stripped off during recurrent movement on the deeper high. Fluvial sand "C" was modified by exposure and erosion during a sea level low stand and recurrent uplift.

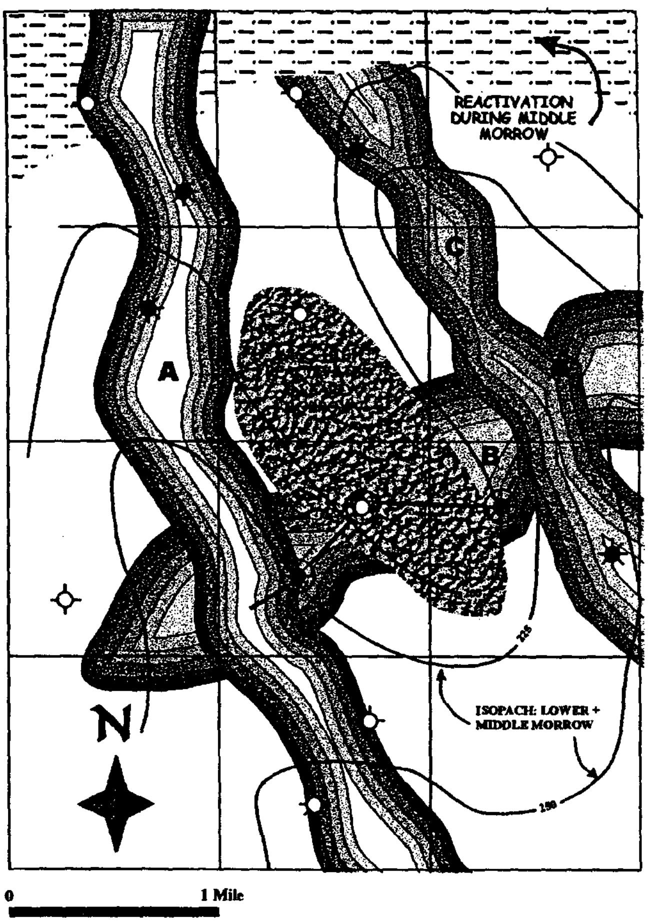


Figure 5. Isopach (in feet) of the Morrow clastics in the area referenced in figure 4, showing abrupt thinning of section around a recurrent, deeper-seated high, and modifications to three major sandstone trends. This map is in an area of Eddy County, New Mexico that was thought to be more tectonically stable during the Morrowan.

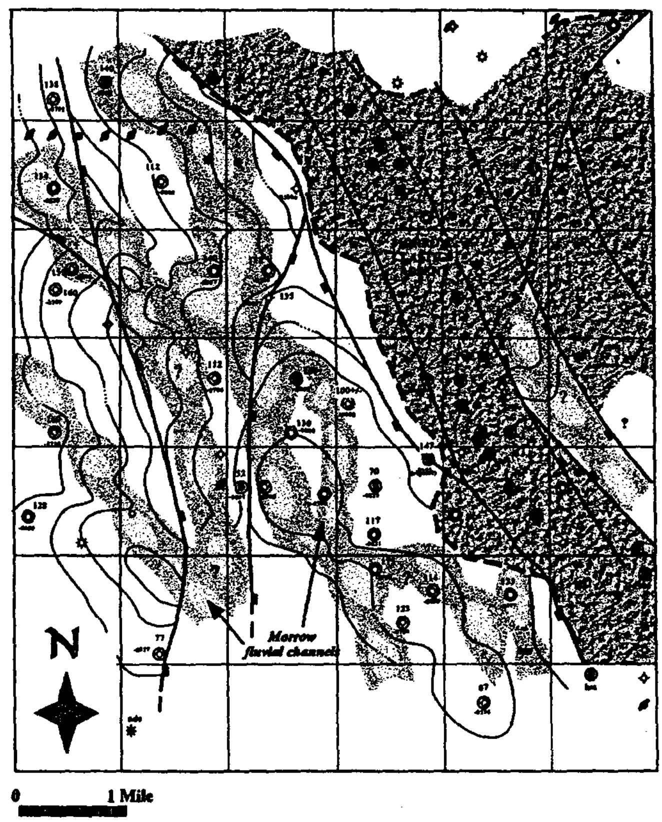


Figure 6. Structure of the top of the Morrow clastics (C. I. = 100 feet) in eastern Lea County, New Mexico, showing the effects of inhibited Morrow deposition due to active tectonic movements and complete removal of remaining Morrow sediments during later widespread exposure and erosion. Major fluvial channel fairways are shown, locally terminating against younger faults. Variable thicknesses of the Morrow clastic section are shown by each deep well.

isting paleo-topographic highs (Figure 4). These changes are not always obvious when correlating logs, but are often suggested by anomalous changes in thickness of the entire Morrow section (Figure 5) and repeated correlation busts. In other areas, such as eastern Lea County, structures were sporadically reactivated throughout the Pennsylvanian (and through the early Permian), in some places inhibiting deposition and in others, resulting in removal of large portions of the Morrow section (Figure 6).

IMPLICATIONS FOR MORROW EXPLORATION AND DEVELOPMENT

The net result of the tectonic and exposure history of the Morrow Formation was a series of subtle to more recognizable intraformational unconformities throughout the Morrow clastics. These unconformities and re-activation surfaces are easily missed with conventional mapping and may be very important when tracing a sandstone reservoir across a field area or in regional reservoir trend analysis. It is clear, therefore, that evaluating the Morrow using simplified models or gross isopach maps is not going to tell the whole story, certainly not to the level of detail required to accurately predict reservoir orientations and new well locations.

When mapping the Morrow, many operators will either choose specific mapping intervals based on what are assumed to be correlative shale markers, or treat the entire section as a single geologic/engineering unit. In either case, presumptions made regarding depositional environments and reservoir trends can be misleading, and can result in either missed opportunities or dry holes. For example, what may appear to be correlative shale

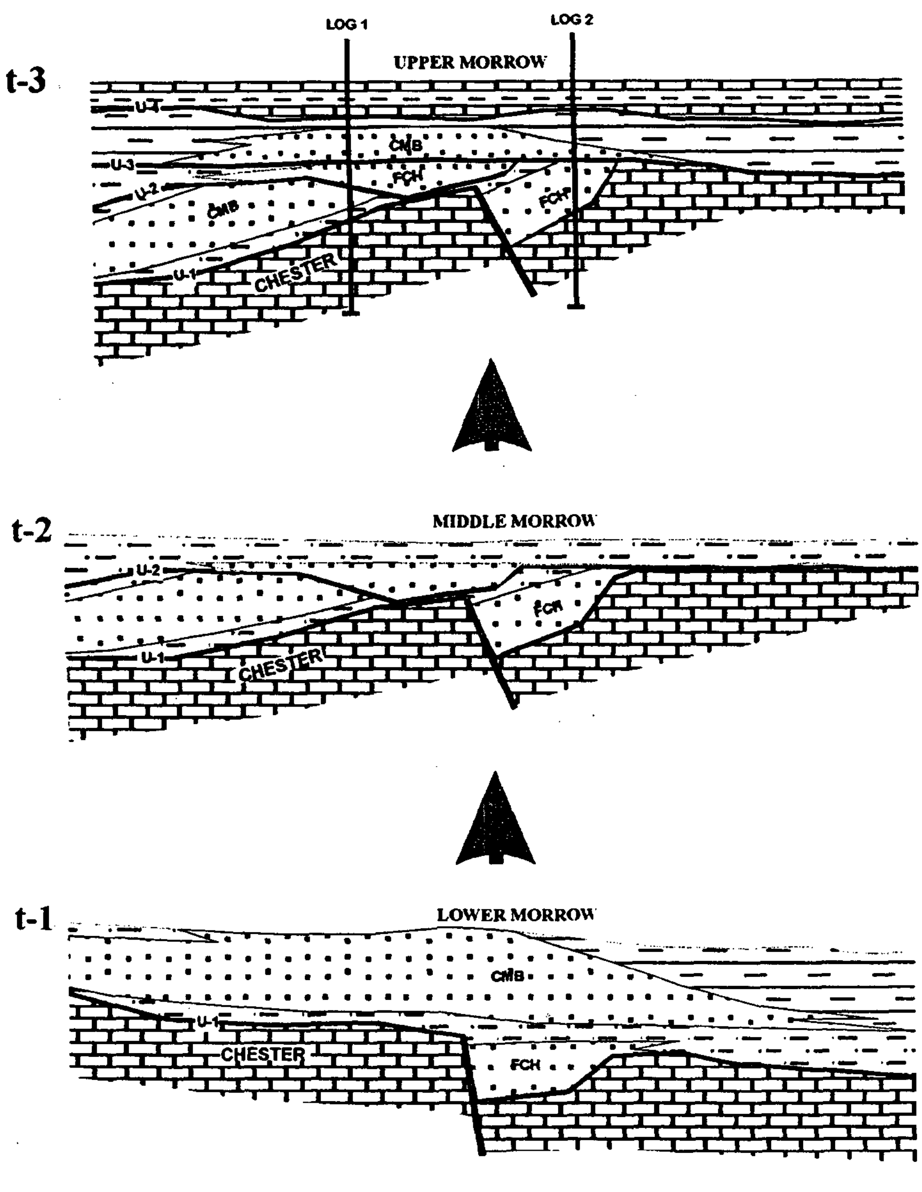


Figure 7. Schematic developmental history of the Morrow clastics representative of conditions observed throughout Eddy and Lea Counties, New Mexico. FCH= fluvial channels, CMB= channel mouth (or deltaic)bars. Intraformational unconformities are labeled U-1 through U-4. Log sections are referenced in Figure 8.

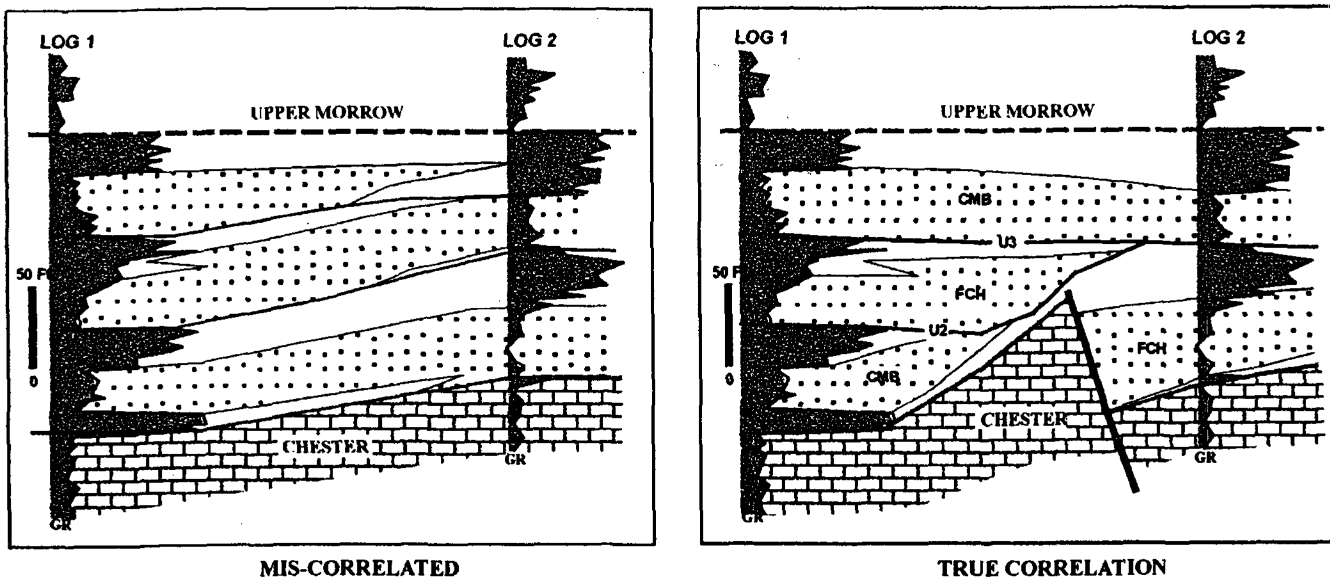


Figure 8. Two interpreted gamma ray log sections from the previous figure. The true correlation accurately reflects conditions shown in Figure 7.

markers may in fact be two entirely different time units, despite similarities in electric log signatures that are used for correlations. To illustrate this point, Figure 7 shows development of a hypothetical Morrow clastics section in present-day Eddy County, New Mexico that is a scenario common to the Morrow throughout the region. Pre-existing Late Mississippian faults in places may have influenced deposition of south-trending fluvial channels in the basal Morrow, during an initial lowstand event. These fluvial sands were superceded by deposition of an east-trending channel mouth bar or deltaic sand during a subsequent highstand. Prior to the end of the lower Morrow, the deep fault was reactivated, and movement along it caused tilting of pre-existing beds. Part of the channel mouth bar sand was eroded by an incised fluvial channel during another lowstand. Sometime in the middle Morrow, another highstand channel mouth bar unit built up and was partially reworked by wave energy as the sea advanced further shoreward.

Figure 8 shows gamma ray log sections through the Morrow illustrated in Figure 7, taken less than one mile apart. This figure illustrates how the Morrow section in closely-spaced wells can be easily mis-correlated based upon log signatures. The mis-correlated interpretation differs dramatically from the true correlation as depicted in figure 7. Reservoir mapping based on the mis-correlation would incorrectly project the orientations of the individual sand bodies that make up the section. For example, south-trending fluvial sands might be correlated to east-trending channel mouth bar sands in adjacent wells, resulting in a map interpretation with erroneous reservoir morphologies. New or offset wells based on such a map may not be optimally located.

EXPLORATION/DEVELOPMENT STRATEGIES

Log correlations alone are not a reliable means by which to map sequences in the Morrow clastics because in many instances, the mapper will inadvertently cross time lines and not correlate time-equivalent units. Biostratigraphic zonation of sandstone sequences is not possible because of the lack of diagnostic fossils. Although it may seem an impossible task to effectively map and correlate the Morrow, there is a vast database of well logs and well cuttings in southeastern New Mexico that, when used together, may help delineate correlative units much better.

The first practices that must be abandoned are the treatment of the Morrow section as a single unit and attempting to map too large an area at a time. Treatment of the whole section as a single geologic unit has two major drawbacks: (1) it blends different depositional environments that can exist in a single well bore or field area, and (2) it fails to recognize any missing section that can arise from intraformational unconformities. Mapping a large area increases the odds of correlation busts, especially in tectonically complex areas. In either case, the explorationist may either underestimate the potentials for multiple reservoir trends or project trends into areas where sands may be missing. The Morrow should be divided into smaller sequences, ideally no thicker than about 25 feet apiece, based initially upon "first pass" correlations using large-scale electric logs. These correlations may not all hold up under further analysis. The next step is to try and identify key time correlative markers with detailed sample analyses, looking for such features as soil horizons, unique and locally continuous marker beds, or laterally persistent lithologic associations. The aim here is to place each general sequence into its proper depositional facies context. Sandstones should be related both laterally and vertically to the facies in which they are encased (Mazzullo, 1999). Once gross depositional sequences are isolated, the log correlations can be adjusted if needed, and isopach maps of each small sequence drawn to determine (1) the precise geometry and orientation of each reservoir, and (2) any potential terminations of reservoirs due to intraformational unconformities. In field extension studies, production histories and bottom hole pressure data (if available) of each Morrow well may be useful in determining pressure separation between zones in adjacent wells that were thought to be correlative. They can also be used to identify suspected permeability barriers that exist between closely-spaced sand bodies that may actually reflect mis-correlated, pressure-separated sand bodies.

CONCLUSIONS

The Morrow Formation of southeastern New Mexico is a complicated depositional system that had been subjected to syn- and post-depositional tectonically-induced changes that are not always recognized or obvious to the exploration or development geologist. Many dry holes or poor producers have been drilled in the Morrow when it seemed a sure bet that "the thickest sand is going off in that direction". Whereas loss of reservoir sands can be related to such phenomena as clay plugging in the case of a fluvial channel, it can also be attributed to re-activation and at times, complete removal at an intraformational unconformity. It is important to know where these surfaces are in a section, and also important to realize that abrupt changes in section can happen within very short lateral distances and more than once within a single well. Consequently, it may be an exercise in futility to try and map too large an area of the Morrow at a time; efforts should focus on smaller mapping areas and vertical sequences.

REFERENCES

Holtz, M. H. And C. Kerans, 1992, Characterization and classification of west Texas Ellenburger reservoirs; Permian Basin-SEPM Publ. 92-33, p. 45-54.

Mazzullo, J. and L. J. Mazzullo, 1984, Detrital and authigenic clay minerals in the lower Morrow sandstones of eastern New Mexico; Transactions Southwest Section-AAPG, Midland, p. 53- 60.

Mazzullo, L. J. and J. Mazzullo, 1985, Geology and clay mineralogy of the Morrow Formation, southeastern New Mexico; SPE/DOE Conference on Low Permeability Gas Reservoirs, Denver, p. 7-14.

Mazzullo, L. J., 1990, Implications of sub-Woodford geologic variations in the exploration for Silurian-Devonian reservoirs in the Permian Basin; West Texas Geological Society Publ.90-86, p.29-42.

Mazzullo, L. J., 1999a, Reservoir geometries and exploration strategies in the Morrow of southeastern New Mexico; Transactions and Abstracts, Southwest Section AAPG, Abilene, p. 53-72.

Mazzullo, L. J., 1999b, Geologic history and reservoir development in the Shoebar Field area, Lea County, New Mexico; Transactions, Southwest Section-AAPG, Abilene, p. 41-51.

Troschinetz, J., 1992, Paleokarst interpretation for Crittendon (Silurian) Field, Winkler County, Texas; Permian Basin-SEPM, Publ. 92-33, p. 134-136.

Wright, W. F., 1979, Petroleum Geology of the Permian Basin; West Texas Geological Society, Publ. 79-71, 98 p.