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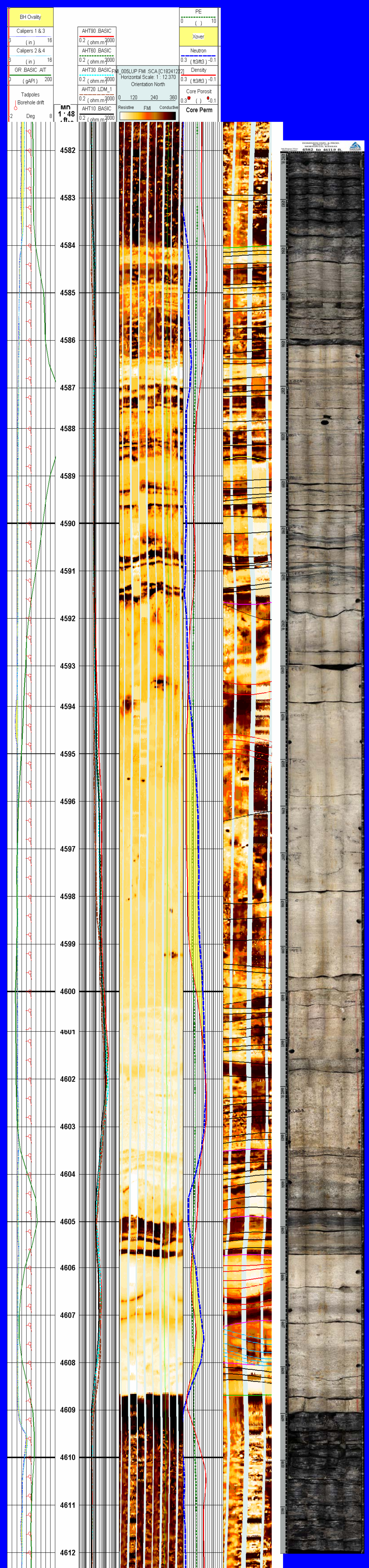
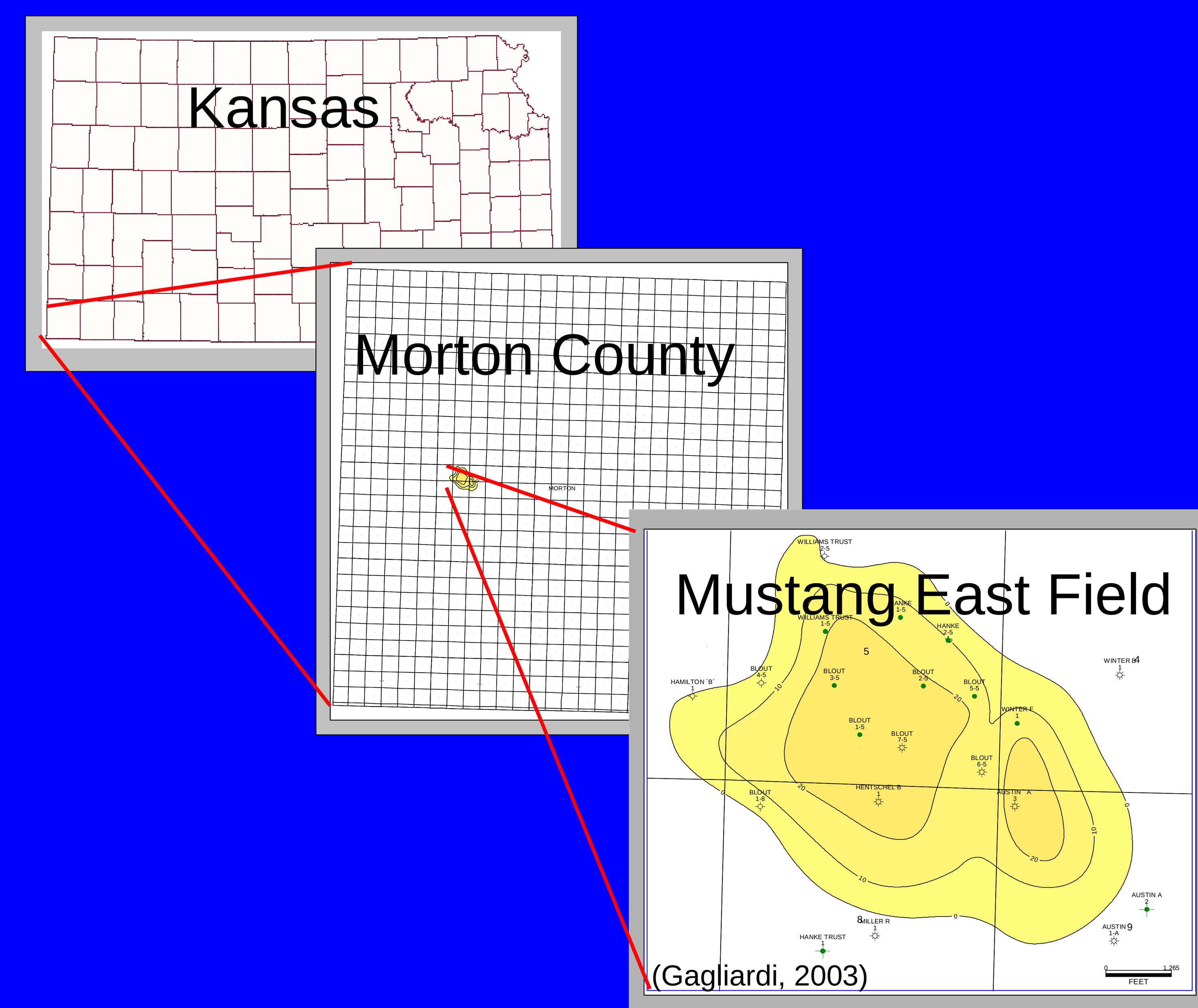
Dominion Blout 7-5

Sequence Stratigraphy and Micro-Image Analysis of the Upper Morrow Sandstone In the Mustang East Field, Morton County, Kansas



To the left is the Formation Micro-Image log of the Dominion Blout 7-5 paired with the 360 degree photo of the cored Upper Morrow sandstone interval from that well bore.

Area of Study



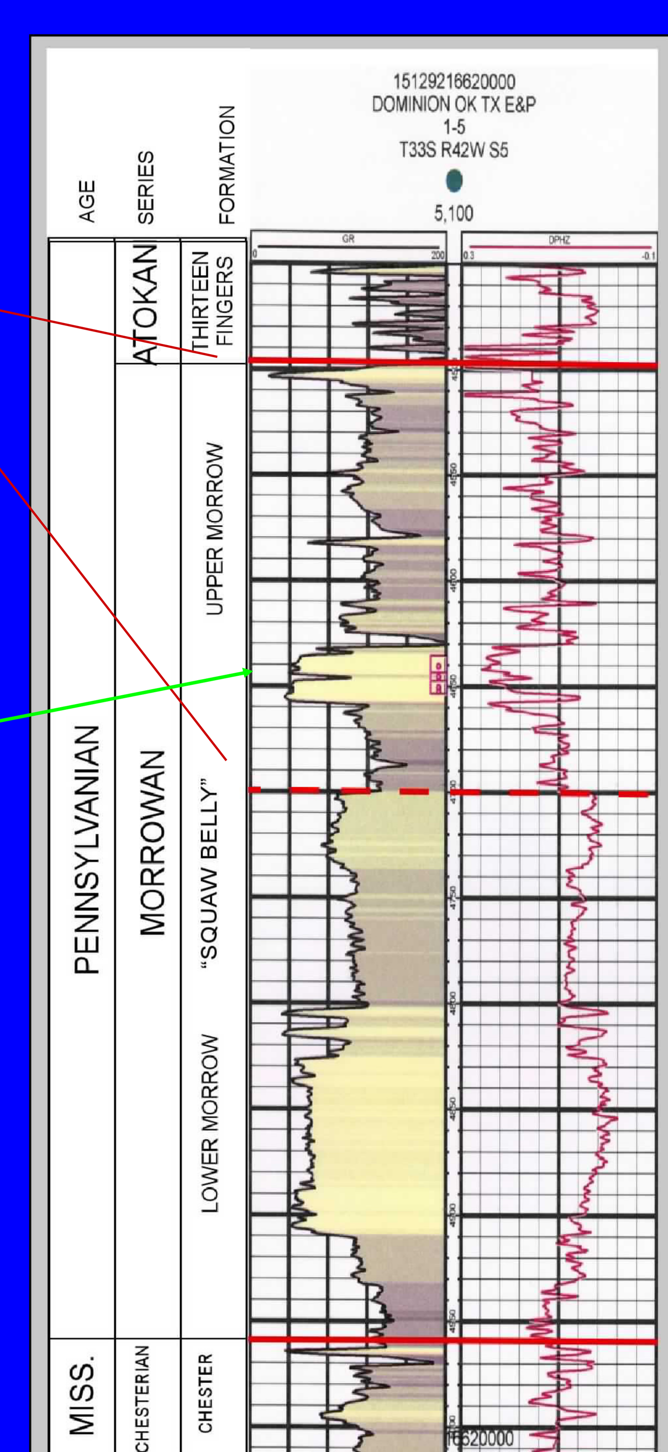
3 Questions

1) Is the sand deposition the result of incised valley -fill or meandering stream point-bar/deltaic deposits?

2) Can core-derived litho-facies be determined and mapped from micro-resistivity logs?

3) Are there sequence-stratigraphic implications to reservoir quality?

Type Log



The Morrowan Series of the Hugoton Embayment is defined on the strata below the Pennsylvanian Atokan 13 Finger Limestone and above the Mississippian limestone (Sonnenberg, 1985). The top of the Morrow is recognized in the subsurface by a change in wireline log signature at the base of the Thirteen Finger Limestone. The Thirteen Finger Limestone is a section of rock with a distinctly “hot” gamma ray signature. The middle Morrow or “Squaw Belly Limestone” (Puckette et al., 1996) is a limestone /calcareous shale unit that separates the sandy lower Morrow section from the upper Morrow, which is predominantly marine shale. The base of the Morrow unconformably overlies Mississippian strata, which become progressively older from south to north across the Anadarko basin and Hugoton Embayment (Wheeler et al., 1990). In Morton County, Kansas and surrounding areas, the upper Morrow interval is also named the Kearny Formation (Luchtel, 1999); the sandstone is called the Purdy sandstone (Sonnenberg, 1990).

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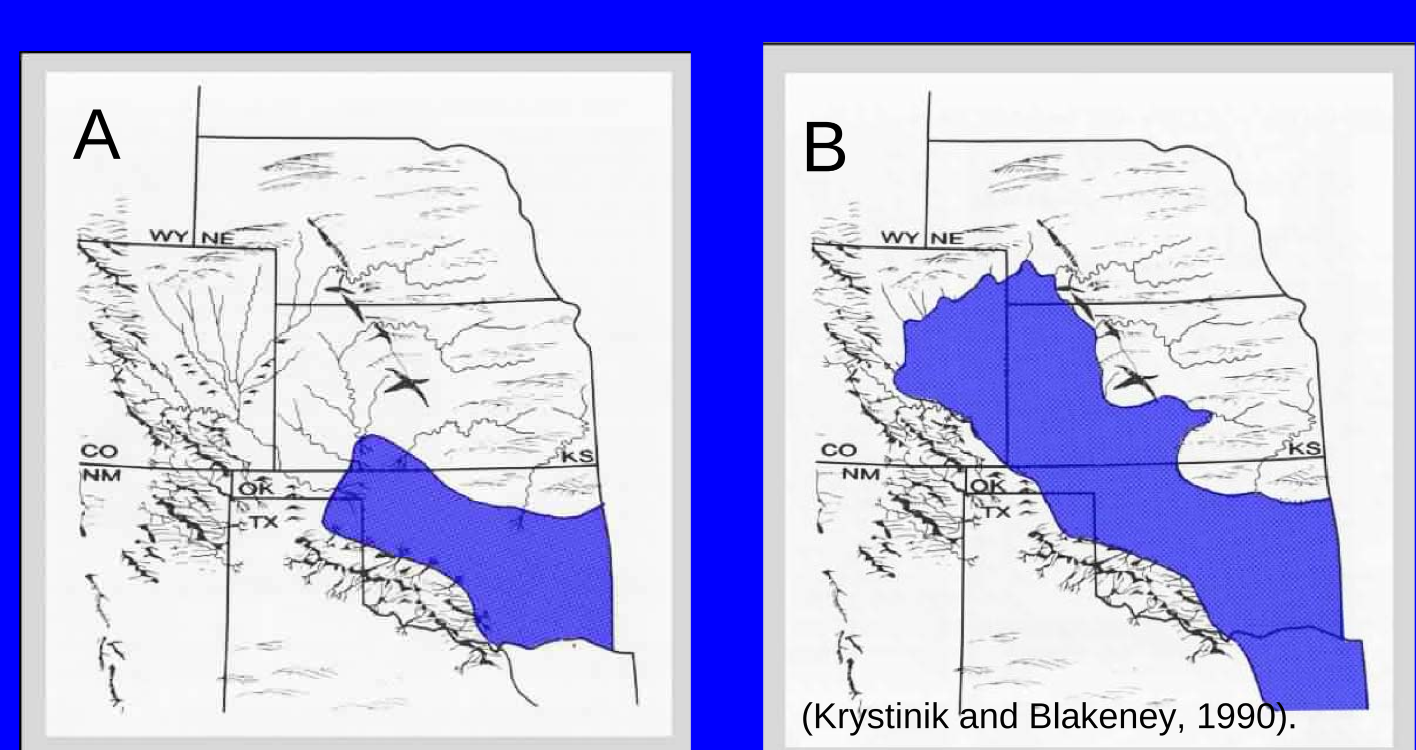
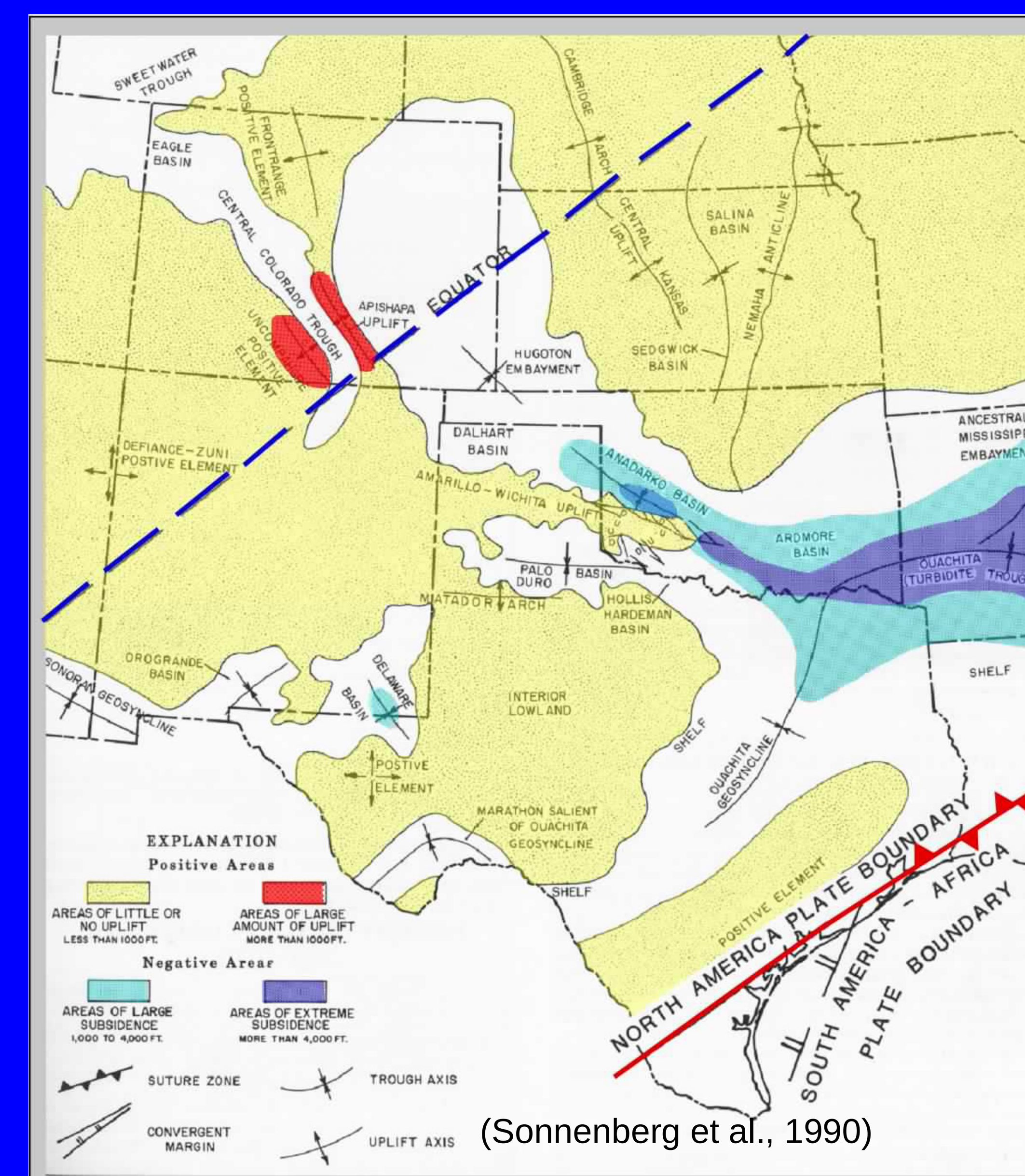
The Pennsylvanian “Morrowan” time of the Mid-Continent

Paleoclimate/Topography

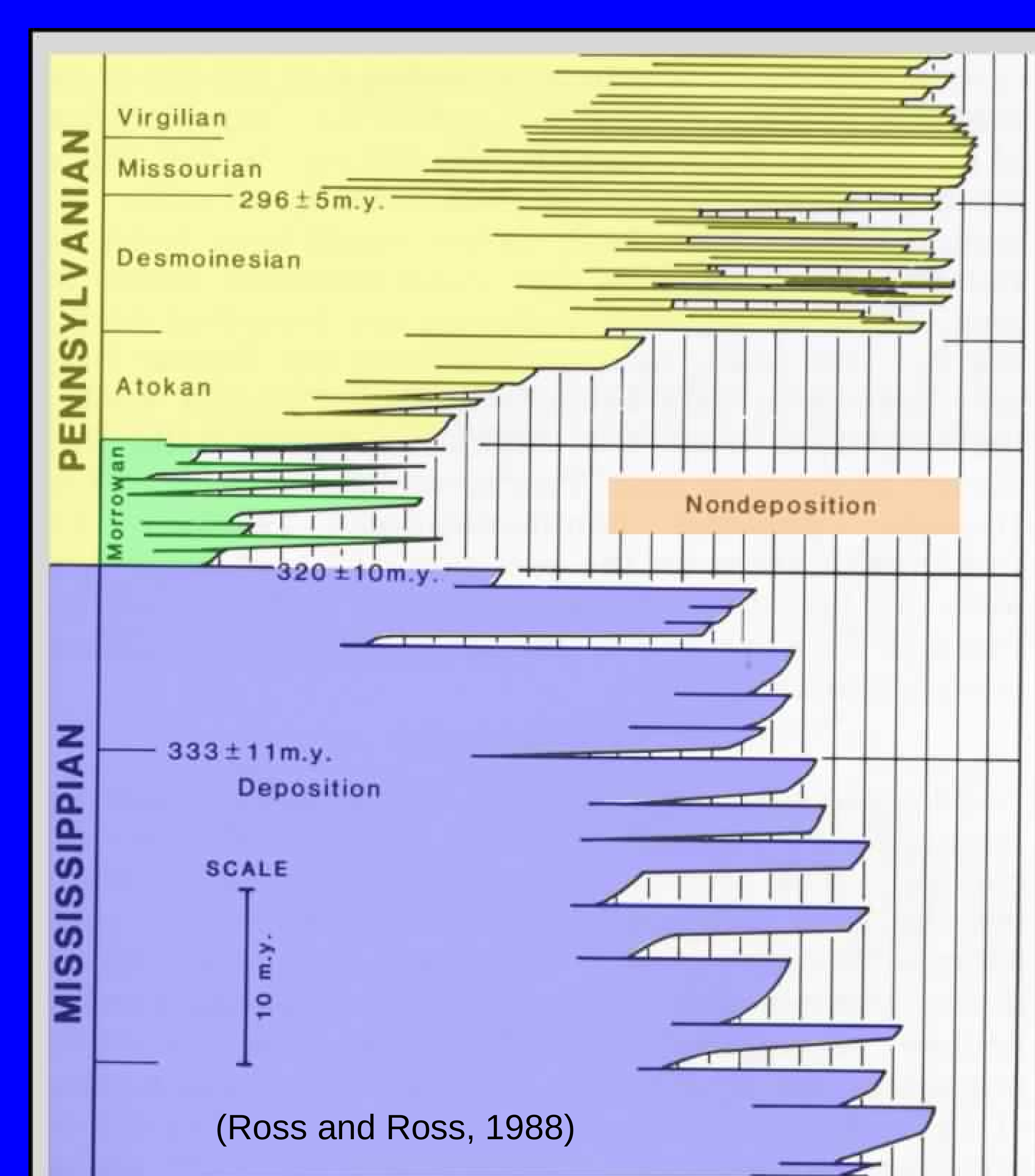
Structural/tectonic activity and climate strongly influenced sediment supply and patterns of deposition during the Pennsylvanian. The geography of the Morrowan series in the Hugoton Embayment during the Pennsylvanian was affected by tectonics and glacio-eustatic change in sea level. Swanson (1979) and Rascoe and Adler (1983) extensively modeled the paleogeography of the Mid-Continent during Morrowan time. The figure below, from Krystinik and Blakeney (1990), is a reconstruction of the paleogeography of the Morrowan sea during periods of sea level low stand (A) and sea level high stand (B). Throughout the Pennsylvanian, the Hugoton Embayment was a broad and relatively shallow shelf area to the north of the Anadarko basin (Krystinik and Blakeney, 1990). The shelf setting resulted in the transportation of Morrowan sediments across a low gradient surface, which made depositional processes highly susceptible to changes in base level (Bowen and Weimer, 2003). Schopf (1975) suggested that the climate of the Pennsylvanian Mid-Continent was tropical to subtropical during the Pennsylvanian. Habicht (1979) placed the Mid-Continent region near the equator during the Carboniferous (central upper figure). The northern shelf was located distal to orogenic belts or uplifts and coarse-sized sediment supply was apparently limited in volume. In contrast, a large volume of coarse-grained sediment was shed from the Wichita Mountain uplift and is evident in the upper Morrowan interval along the mountain front. Even though the Mid-Continent region was located near the equator during the Pennsylvanian, it is suggested that sediments of the Morrow Formation were deposited during a period when the Earth’s climate was much cooler than at present (Crowell, 1999). These “ice-house” conditions may have limited the intense erosion rates associated with tropical climates, further restricting sediment supply to the Hugoton Embayment.



(Krystinik and Blakeney, 1990).



(Sonnenberg et al., 1990)



(Ross and Ross, 1988)

Morrowan Sediment Supply, An Underfed System?

The Morrowan system of the Hugoton Embayment appears to have been generally sediment starved or underfed. Rising base level, resulting from eustacy and/or subsidence, outpaced sedimentation rates to produce estuarine environments deep inside the Morrowan incised valleys. Continued invasion of the transgressing seas resulted in open marine sedimentation (Puckette, 1993) and completed the encasement of the incised valley complex within marine shales. Three lines of evidence suggest the Morrowan sediment dispersal system was underfed: (1) very little coarse-grained material (sand, granules, or pebbles) was deposited on the northern shelf of the Anadarko basin during Morrowan lowstands. The lack of extensive lowstand deltas or submarine fans implies that very little sand-sized siliciclastic sediment was passing through the incised valleys. Deltaic deposits within the upper Morrowan interval are scarce in the deeper parts of the Anadarko Basin. When Morrowan deposits are compared to those in the Desmoinesian Red Fork (Puckette et al., 2000) and Skinner intervals (Puckette and Al-Shaieb, 1989) it becomes obvious that sediment supply during the Morrowan was severely limited in volume and distribution. (2) Upper Morrowan sandstones are almost all completely confined to the incised valleys. The confinement of sand-rich lithofacies to channels indicates that as seas transgressed the exposed northern shelf of the Anadarko basin, the supply of coarser sediment was limited and the valley provided adequate accommodation space to contain it. As a result, sediments could not escape the valley and spread beyond the incised valley walls. (3) Cored Morrowan intervals in the Oklahoma Panhandle contained abundant echinoderm, bryozoa, and brachiopod fragments within the estuarine sands (Puckette, 1993). The marine organisms were carried far up the Morrowan incised valleys contemporaneously with sand deposition, indicating that marine processes were dominating fluvial ones in the estuary. The bioclastic fragment-rich facies was not present in the cored upper Morrow intervals of the Mustang East field.

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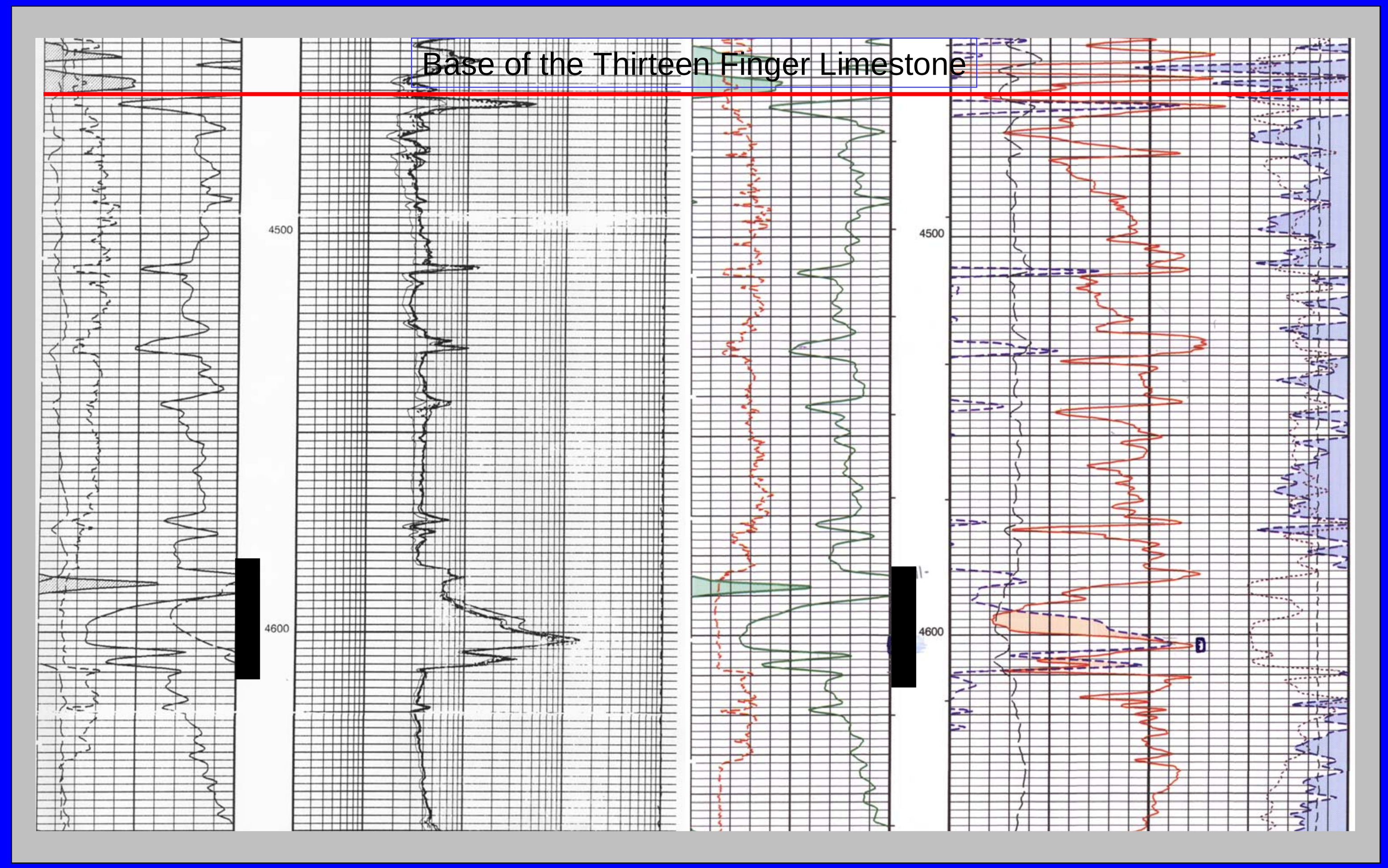
Core-Derived Lithofacies of the Upper Morrow Sandstone From the Mustang East Field

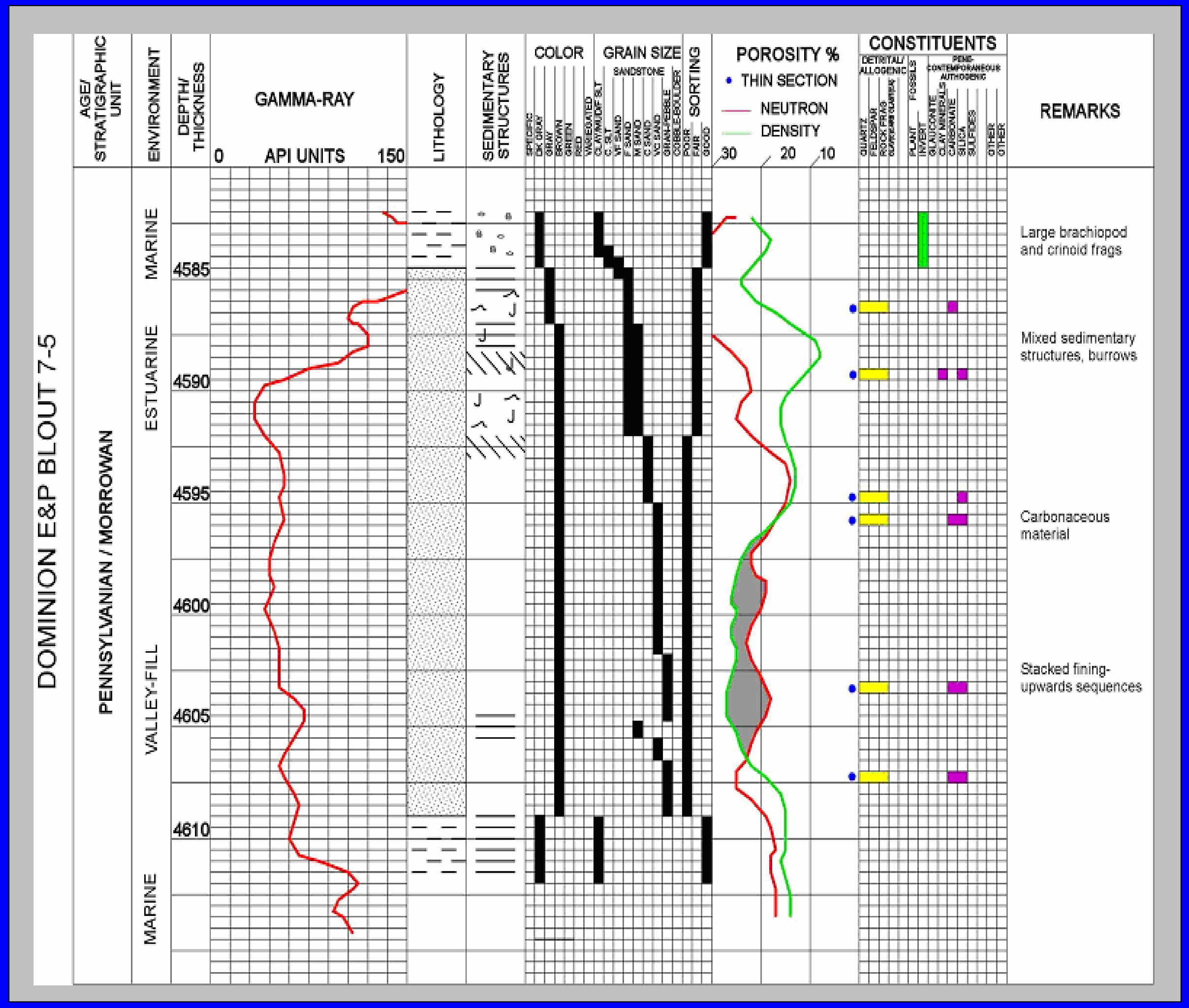
Dominion Blout 7-5

Conventional Logs



Above are the Induction and Neutron-Density logs over the Upper Morrowan interval of the Blout 7-5. The Black box indicates the cored interval.

Petro Log



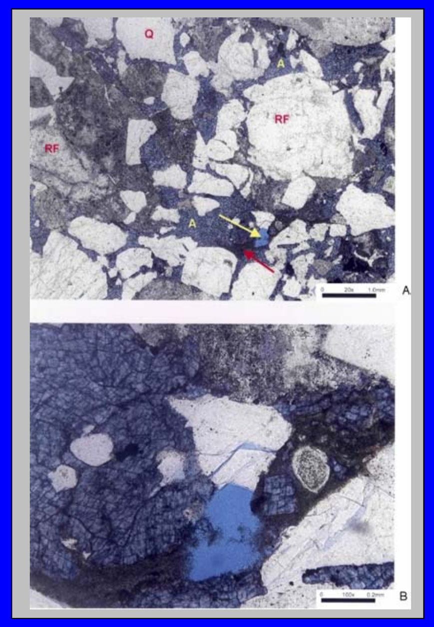
The Petro Log is a graphic summation of electric log properties, thin section analysis, and geological observations of the core.

Lithofacies

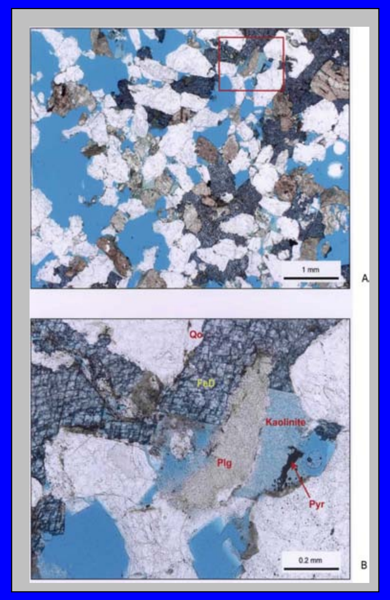
Lithofacies	Sedimentary Structures and Depositional Facies	Reservoir Characteristics
Fluvial (F)		
F1	Martix-supported paraconglomerate. *High current-energy stream.*	Generally poor quality. Low porosity and permeability are due to abundant cement and psuedomatrix.
F2	Coarse-grained sandstone to conglomerate. This package may contain trough or tabular cross-bedding and occurs in staked finning-upward sequences. *High energy braided stream.*	Generally fair to good-quality. Primary and enlarged intergranular porosities are common.
F3	Ripple to low angle cross-bedded, fine to coarse-grained sandstone with occasional clay clast and carbonaceous material. *Meandering stream.*	Generally fair to good-quality. Porosity reduction as a result of cementation and/or pore filling authigenic kaolinite.
F4	Fine-grained sandstone occasionally interlaminated with silty, shaly or coaly intervals. *Channel abandonment.*	Generally poor to fair-quality. Significant pore space is filled with matrix.
Estuarine (E)		
E1	Interbedded fine to medium-grained sandstone and shale containing abundant trace fossils. *Mid-Estuarine environment: Low energy.*	Generally poor-quality. Low porosity and permeability are due to abundant cement and psuedomatrix.
E2	Fine to medium-grained, burrowed sandstone and dark shale that is interbedded with thin, coarse-grained sandstones. *Upper-Estuarine environment: Tidally influenced with variable energy and possible fluvial input.*	Generally fair-quality. Primary and enlarged intergranular porosities are common.
Marine (M)		
M1	Thinly laminated black shales and claystone. Calcareous intervals contain abundant fossils. *Low-energy environment: Offshore shelf setting.*	
M2	Fine to coarse-grained, calcite cemented and fossiliferous sandstone. *High-energy environment: shallow marine.*	Poor-quality reservoir rock due to extensive calcite cement

Lithofacies designation, description, and reservoir qualities (Al-Shaieb and Puckette, 2002). Six of the eight lithofacies described by Al-Shaieb and Puckette were present in the Mustang East cored intervals. The absent lithofacies were the M2 (marine sandstone) and the E2 (fluvial-influenced estuarine deposits).

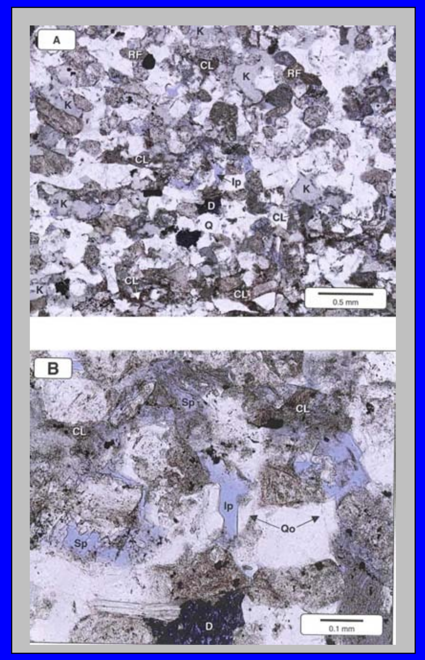
Fluvial Sands in Thin Section



Two photomicrographs of the F1 lithofacies in the Blout 6-5, 4556.5 to 4556.8 ft. (A) Overview of poorly sorted facies F1. Q quartz, RF rock fragment, A ankerite cement, yellow arrow-open pore, red arrow-detrital (B) Light blue-secondary dissolution pore, dark blue-ankerite cement. Cross-polarized light (CPL).



Two photomicrographs of a typical F2 sandstone in the Blout 7-5 at 4596.0 ft. (A) Photomicrograph of facies F2. Red box indicates enlarged section B. (B) Ferroan dolomite (FeD), Kaolinite, and Quartz overgrowths (Qo). Light blue represents epoxy cemented pores (PPL).



Two photomicrographs of a typical F3 sandstone in the Blout 3-5 at 4626.5 ft. (A) Photomicrograph of facies F3. Quartz (Q), rock fragments (RF), undifferentiated clays (CL). (B) Enlarged view illustrating quartz overgrowths (Qo), clays (Cl) and secondary porosity (PPL).

Two photomicrographs of a typical F2 sandstone in the Blout 7-5 at 4596.0 ft. (A) Photomicrograph of facies F2. Red box indicates enlarged section B. (B) Ferroan dolomite (FeD), Kaolinite, and Quartz overgrowths (Qo). Light blue represents epoxy cemented pores (PPL).

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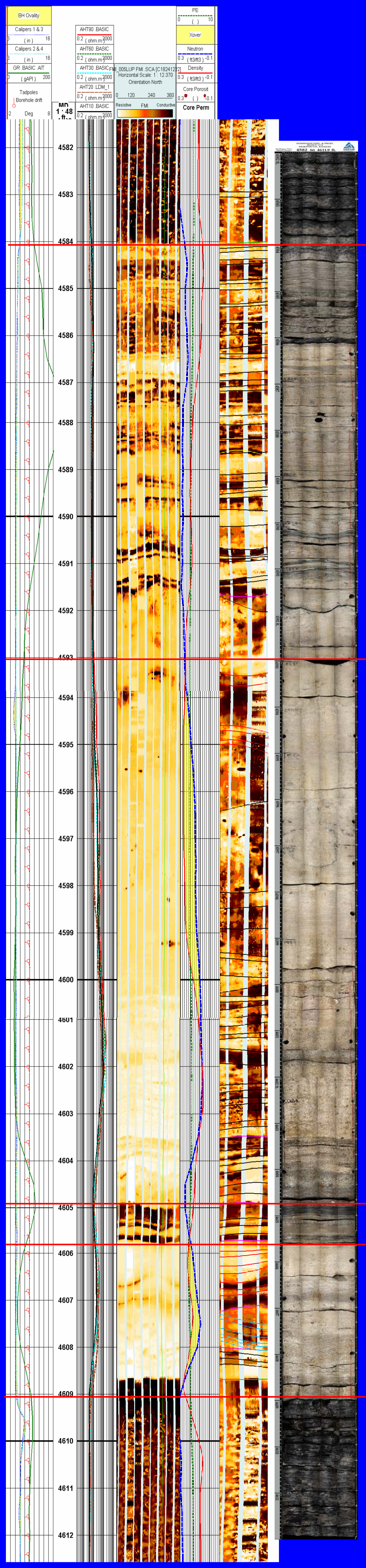
Micro-Imaging of the Upper Morrow Sandstone From the Mustang East Field

Dominion Blout 7-5



To the left is the Formation Micro-Image log of the Dominion Blout 7-5 paired with the 360 degree photo of the cored Upper Morrow sandstone interval in that well bore. Individual lithofacies are noted to the right of the core photograph.

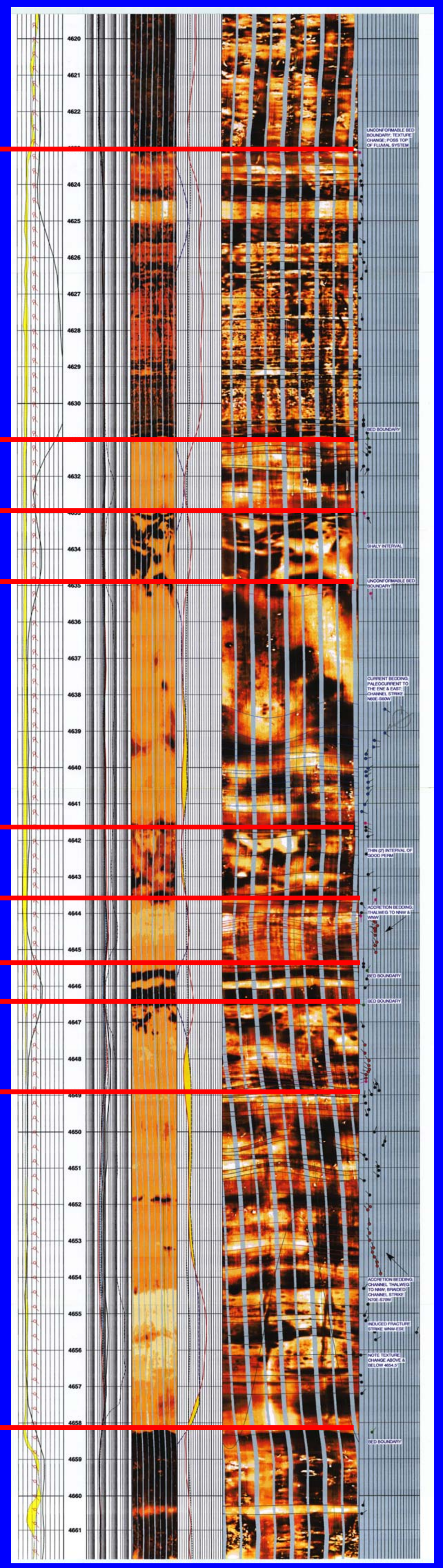
Lithofacies Micro-Image Properties

FACIES	Micro-Image Log Characteristics
F1	Highly resistive (white to yellow) containing slightly less resistive (dark yellow to orange) clay clasts. Always located as a sharp contact over facies M1. * Most easily identified in conjunction with the dynamic image.
F2	Highly resistive (white to orange). Most commonly a yellow hue. Dip direction “tadpoles” show a bi-directional pattern indicating vertical accretion.
F3	Highly resistive (white to orange). Most commonly a yellow hue. Dip direction “tadpoles” show a red over blue sequence indicating lateral accretion.
F4	Highly conductive (black to dark orange) interval found interspersed within the F2 facies. Often found capping a fining-upward sequence.
E1	Black to white (mostly orange hues). Differing orange hues represent the sand/mud interaction in the estuary
M1	Highly conductive (black to dark orange). Found beneath erosional contacts with fluvial facies and overlying the siliciclastic intervals.

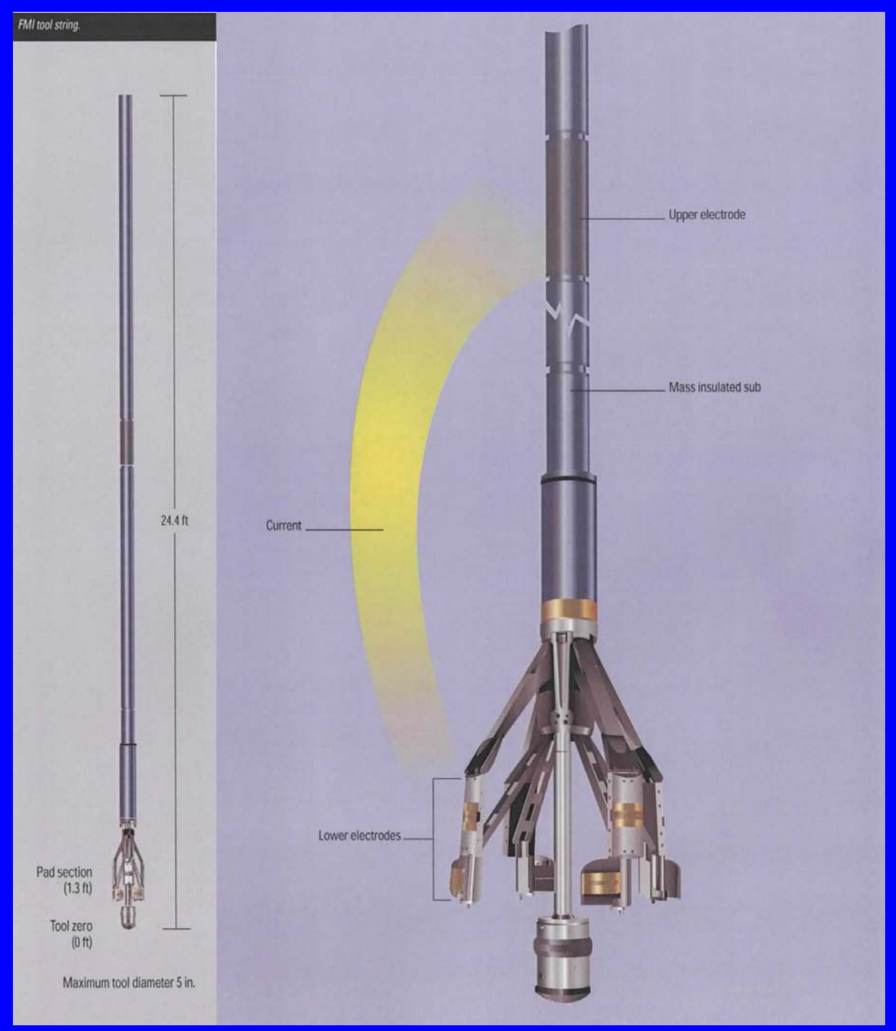
Micro-Image properties of observed lithofacies are recorded In the above chart. Conductivity (measured by color), bedding contacts, dip directions and micro-resistivity textures were all considered as components for core calibration.

Dominion Blout 1-5

To the right is the interpreted Formation Micro-Image over the Upper Morrow Sandstone from the Mustang East field type log, the Blout 1-5. The Blout 1-5 exhibits more textural elements than the Blout 7-5 but the overall stacking pattern of Marine-Fluvial-Estuarine-Marine is still present.



Micro-Imaging Tool



(Schlumberger, 2002).

Micro imaging tools are run in conductive, water-based muds. The Schlumberger FMI tool (left) applies an alternating current from an upper electrode that is recorded by 192 lower electrode buttons (24 buttons x 8 pads). The resultant measurements provide 0.2 inch resolution resistivity images over 80% of an eight-inch borehole. Resistivity resolution on that level will record subtle changes in rock properties associated with composition, texture, cementation, and orientation of the strata. The current induced by the sonde consists of a high-resolution and low-resolution component. The high-resolution component dominates the image because the values change from button to button (Schlumberger, 2002). The low-resolution component is represented by gradually changing background values. By The image tool also records depositional surfaces and bedding planes. These measurements are instrumental in determining paleocurrent, accretion directions, and tectonic dip.

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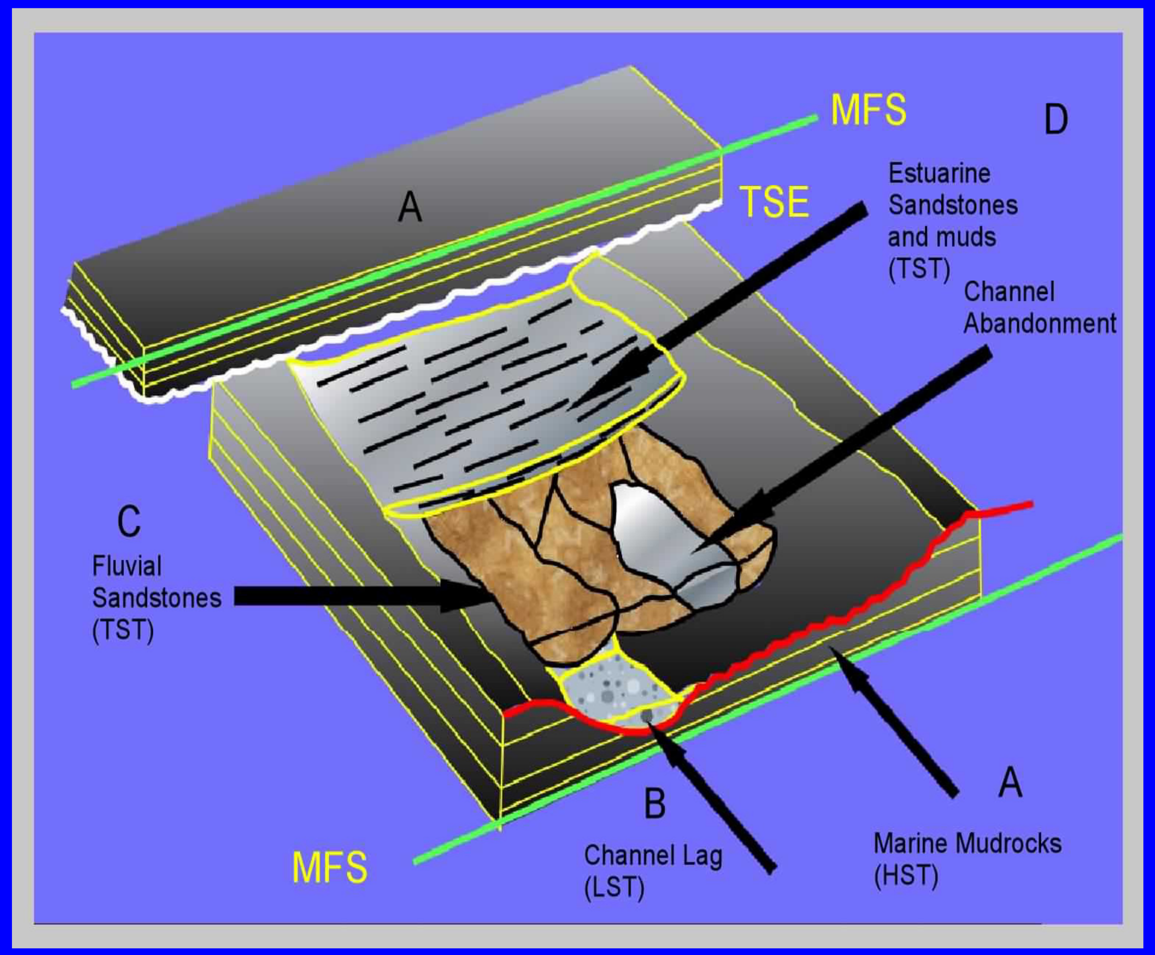
Conclusions and Observations on the Deposition of the Upper Morrow Sandstone in the Mustang East Field

1)



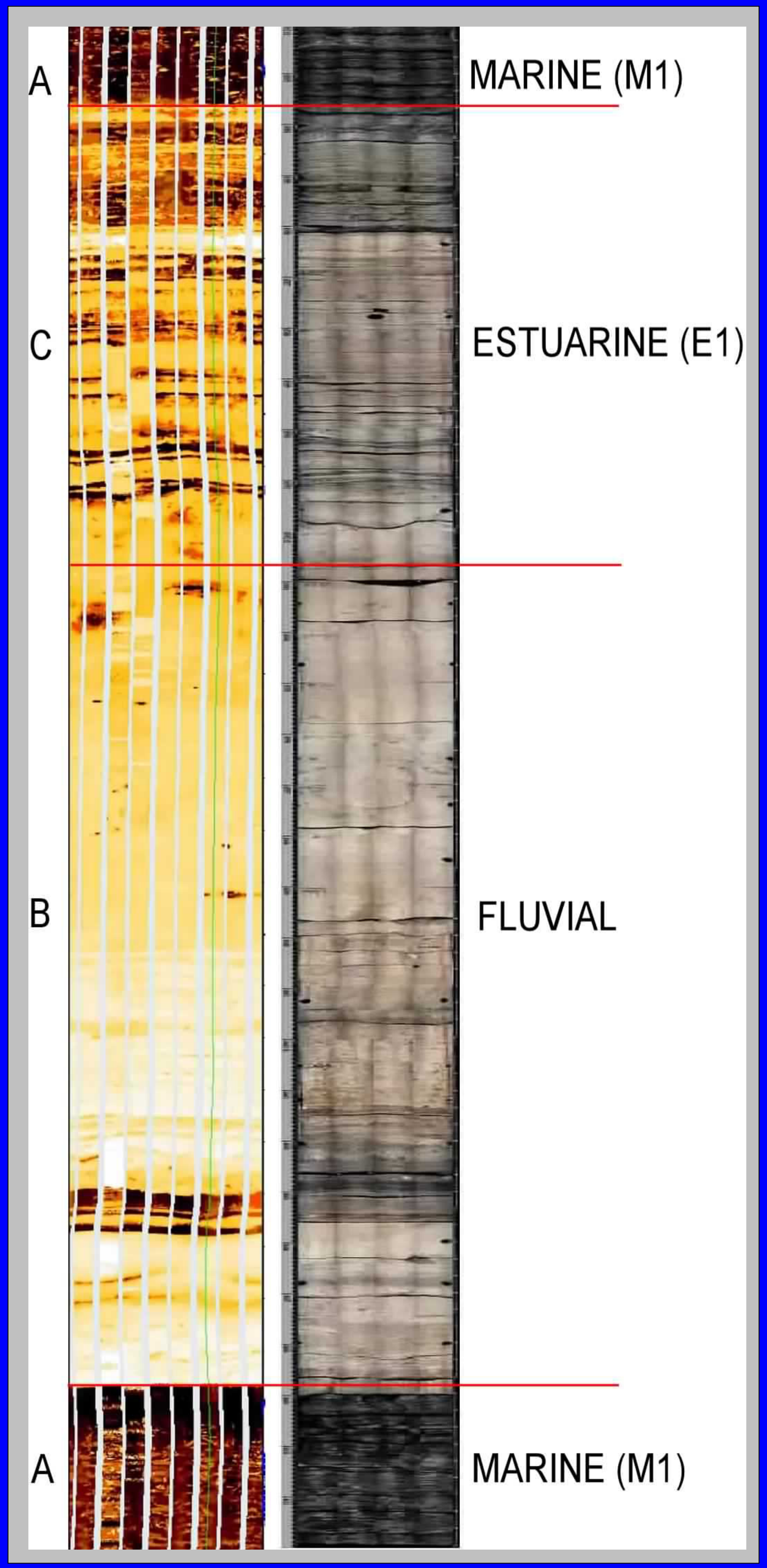
(modified from Wheeler et al., 1990)

The figure to the left is a three-dimensional block diagram from Wheeler et al. (1990) that illustrates an idealized Morrowan incised valley-fill complex. During periods of sea level lowstand, Morrowan fluvial systems would erode marine shelf rock / sediment (interval A) and at the point of maximum incision create the LST erosional unconformity that becomes a sequence boundary. During the LST, most siliciclastic sediments bypass the shelf completely and are transported to the deeper basin. Little evidence supports the formation of traditional lowstand wedges in Hugoton embayment or the Anadarko basin though. This lack of broad deltaic or submarine fan deposits on the northern flank of the basin may suggest that the coarse siliciclastic sediment eroded at the headwaters of Morrowan streams never reached the basin. However, deposition inside the valley during the LST appears to be restricted to a thin veneer of clay pebble-rich conglomerate. These are interpreted as the continental deposits during the LST (interval B). It is likely that most of the sediment produced in the upper Morrow drainage basins was mud or silt derived from the erosion of sedimentary rocks, which was easily transported through the system and deposited in the Anadarko basin.

The filling of the valley by fluvial and estuarine sediment was induced during the transgressive phase by a rising base level. As these incised valleys began to be inundated with the rising seas, the coarser-grained sediment could no longer remain entrained as the stream energy decreased. Lacking the ability to transport sediment past the shelf, the incised valleys became sediment catchments for coarser-grained material. Coarse-grained sand, pebbles and granules were the first to be deposited (interval C). As sea level continued to rise the coarse-grained fluvial sandstones were overlain by estuarine deposits (interval D) in the slightly deeper, less turbulent portion of the incised valley. Lastly, marine mudrocks (interval A) once again covered the siliciclastic sediments as the system returned to highstand base level.

Above is a photo of the estuarine facies from the Dominion Blout 7-5. As a non-regional field study the presence of this bioturbated, interlaminated sand/mud facies is very important in the conclusion that the sediments were deposited within an incised valley. The abnormally "hot" gamma-ray values, lack of woody debris and the high angle of deposition suggest an estuarine environment deposited in bar-type fashion within a limited area.

2)



The static image logs of the upper Morrow sandstone interval were paired with the gamma-ray curve for 11 wells in the field. Careful observation of image log responses to core-derived lithofacies indicate three discernable facies which may be mapped on a field wide basis: (1) Marine (left figure, interval A), (2) Fluvial (left figure, interval B), (3) Estuarine (left figure, interval C). The Blout 7-5 well was key in designating these facies. The Blout 7-5 cored interval contains all three mapable facies. The sandstone-rich interval is bounded on the top and bottom by marine mudrock.

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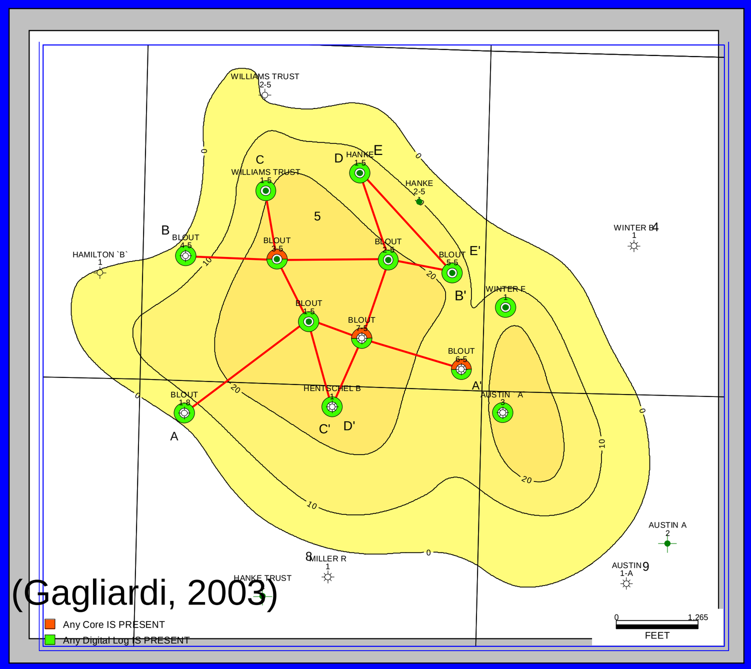
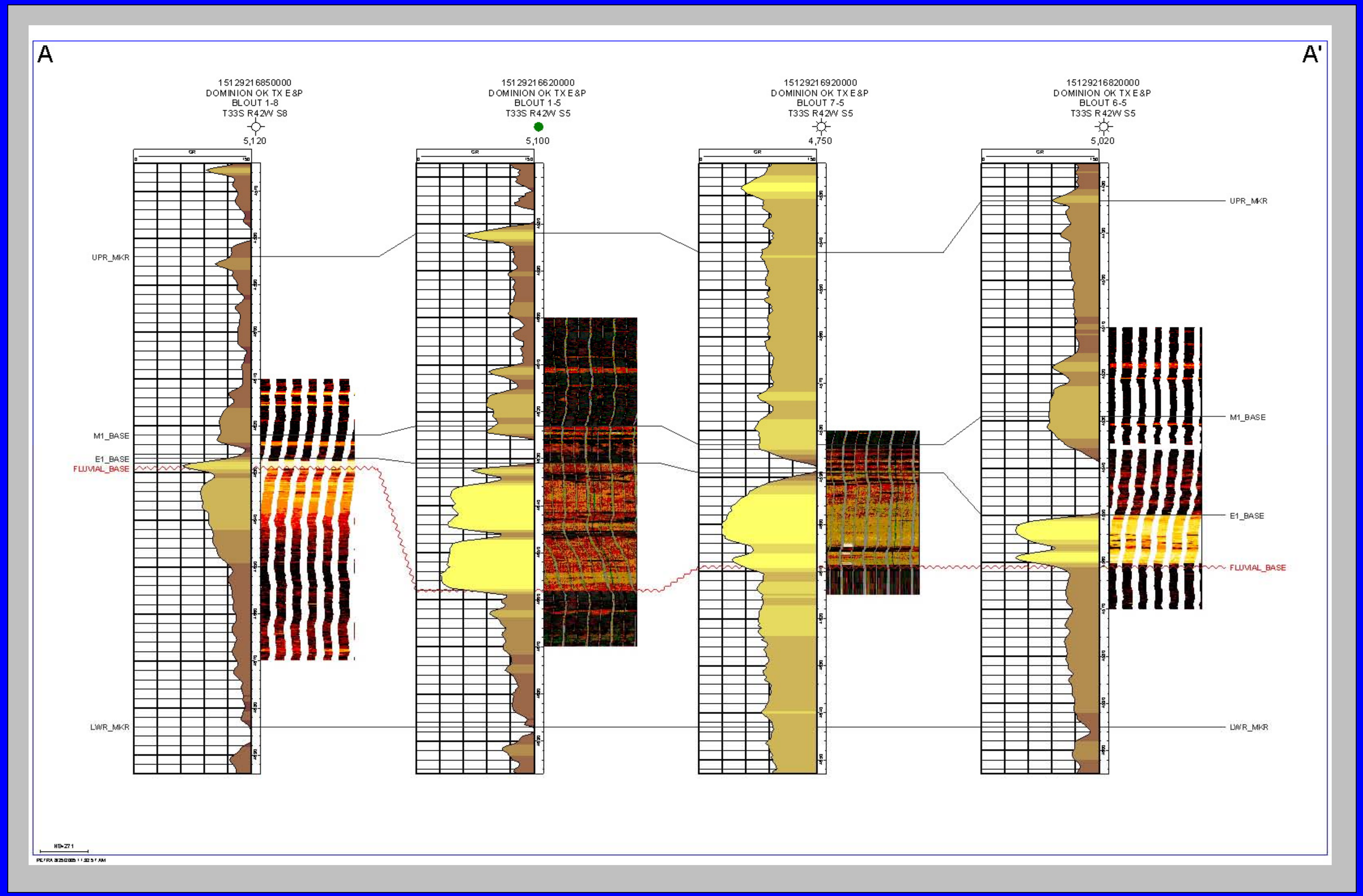
Conclusions and Observations on the Deposition of the Upper Morrow Sandstone in the Mustang East Field (cont.)

2) cont.



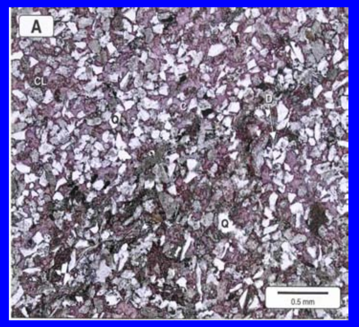
(Gagliardi, 2003)

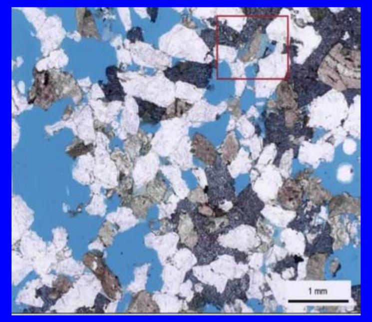


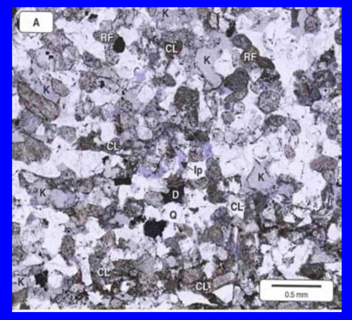
Core calibrated Micro-Image logs can be used to identify lithofacies in the sub-surface on a well by well basis. However, the nature of the Upper Morrowan sandstones in the Mustang East field did not lend itself to useful mapping of individual lithofacies. The amalgamating, meandering and self-destructive nature of the Morrowan sandstone studied made facies level correlations improbable, even from core to core. Although the mapping of individual lithofacies proved to be ineffective in this area the mapping of lithofacies “assemblages” (marine, fluvial and estuarine) yielded promising results as shown in cross section A A’ above. Cross-section A-A’ shows an interpreted valley edge to the west in the Blout 1-8 well. The subsequent wells in the easterly direction (Blout 1-5, Blout 7-5, and Blout 6-5) all exhibit the same image-log derived facies stacking pattern. The basal marine facies in these wells are in unconformable contact with the overlying fluvial facies. The fluvial facies, while of varying thickness, is overlain by an estuarine facies that grades back into marine mudrock. Note: as a result of accommodation space the wells that exhibit thick sections of fluvial sediment have relatively thin veneers of estuarine deposits before the depositional environment changed back to an open marine system. Wells with relatively thin fluvial deposits have thicker estuarine deposits before returning to an open marine system.

3)

FACIES	E1 (5)	F1 (4)	F2 (43)	F3 (2)	F4 (3)
POROSITY	8.48	5.38	15.73	11.95	8.933
PERMEABILITY	0.064	0.390	114.036	0.444	1.762







The table to the left is a graphical representation of reservoir quality (porosity and permeability) by recognized facies (designated on the photos) within the Mustang East field. The fluvial sandstones contain stacked fining-upward sequences that consist of pebble and granule conglomerate and coarse-grained sandstone. These sedimentary features are often associated with braided stream deposits, but could represent truncated meander deposits. Facies F2 stands out as the better reservoir, it has relatively high porosity and permeability. The greater cementation and abundance of pore filling kaolinite/ankerite limit reservoir quality in the F3. The F3 facies contains quartz overgrowth cementation. The F4 facies contains silty, shaly, or coaly intervals that not only reduce porosity, but also hinder connectivity of the pore spaces. The other potential reservoir sandstone in the valley-fill package is the estuarine facies. This is often a low porosity and permeability facies due to calcite/dolomite to ferroan dolomite (ankerite) cementation. The marine facies M1 is not a reservoir rock. Facies M1 provides an excellent seal for reservoirs and may serve as a hydrocarbon source rock (Sonnenberg, 1985; Bolyard, 1989).

Fluvial facies F2 is unquestionably the best reservoir rock in the Upper Morrowan system within the Mustang East Field. Lithofacies F2 could have been deposited in either of two ways: 1) as a stand alone coarse-grained, fining upward unit, lithofacies F2 appears to be a braided stream accretionary deposit. 2) lithofacies F2 may also represent the lower portion of a meandering stream deposit. The amalgamating, meandering and self-destructive nature of the Morrowan Sandstone may explain why the finer-grained facies associated with these types of deposits are seldom preserved in the Upper Morrow. Above are two photos of the Red River. The photo on the left is at ground level and the river appears to be a braided stream (multiple channels, longitudinal bars, mid-channel bars).The photo on the right is an aerial photo that shows large meander bends with the formation of point bars. This is a modern example of how the ancient Morrowan streams may have behaved. Neither meandering or braided but possibly both depending on the flow regime.

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