PS Examining Detailed Facies and Rock Property Variation in Upper Cretaceous, Tight Gas Reservoirs, Pinedale Field, Wyoming*

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Abstract

The giant Pinedale gas field is located in the northern Green River Basin, Wyoming (Figure 1). Gas is produced from ~5500 ft (1675 m) of Upper Cretaceous fluvial sandstones of the Lance Formation, Upper Mesaverde Group, and the Paleocene "Unnamed" unit – collectively known as the "Lance Pool". The reservoir is classified as tight gas, with sandstone porosity generally <10% and with micro-Darcy permeability. Over 4000 feet (1220 m) of core have been examined to better characterize facies for correlation to rock properties. These detailed facies and rock property relationships have been incorporated into reservoir models to influence development decisions on down-spacing and completion intervals.

Two main types of reservoir sandstones include river channel deposits and overbank crevasse splay sands. Channel sands display classic fining-up sequences (Figure 2). These sequences have been sub-divided into four facies: (1) channel base lags - "Cl", (2) basal bar or active channel fill - "Ca", (3) upper bar or partial abandonment fill - "Cb", and (4) soil-modified bar top - "Cu". Characteristics of these facies are described in more detail in Figure 2 and Figure 3. Splay sandstones are typically very-fine grained and highly cemented, with lower reservoir quality.

Despite an overall similarity in fluvial facies character, there are variations in sand percent, stacking pattern and overbank environments both vertically and laterally around the anticline (Figure 4). Overbank mudstones and siltstones contain many indications of soil formation, e.g. rooted zones, granular, crumb and blocky peds, caliche nodules, zones of calcite enrichment and depletion, and lack of undisrupted lamination. Rooting and ped structures are ubiquitous. However, other mudrock features vary in their abundance in the vertical section, providing clues to overall environment (Figure 4 and Figure 5).

The lower, “Mesaverde” interval has less sand percent, thinner channel sands, thicker intervals of splay sands, and overbank mudstones that are more carbonaceous and bioturbated. This suggests a higher-accommodation, lower coastal plain setting with poorly drained floodplains. The Lance Formation contains thicker channel deposits with varying amalgamation. Especially prominent is the gradation from thick, amalgamated “Middle Lance” sandstones in the north, to mud-dominated Middle Lance towards the south. Lance Formation overbank muds range from more carbonaceous at the base, to more oxidized (presence of red and red-green mottling) with common caliche nodules at the top indicating transition from poorly to well-drained flood-plains. The Unnamed Formation channel deposits contain arkosic gravel bars, indicating exposure of the granitic core of the Wind River Range, as indicated by Law and Spencer (1989).

Despite significant compaction and cementation leading to low porosity and permeability, we can demonstrate good correspondence of core and log petrophysical properties to facies (Figure 6 and Figure 7). Detailed core examination can explain many features on logs. Figure 6 shows how mud clast lags have high gamma ray and low resistivity, but the matrix sandstone between the mud clasts can have very good permeability (Figure 7). We created continuous calcite reaction logs during core description by indicating how vigorously the core reacted with HCL drops. The low porosity zone at 9365 ft in Figure 6 can be seen to correspond with higher acid reactivity, indicating a higher proportion of carbonate cement. These core observations have been confirmed via XRD and petrographic analysis. The correspondence of core porosity to log-derived porosity in Figure 6 is very good. The correspondence of core permeability to log-derived permeability (from poro-perm cross-plot regression) is more variable, but the trends are well captured.

There is a good correspondence of stress-corrected log10 permeability to porosity within sandstones, and it is clear that porosity is the main contributor to permeability at the core scale (Figure 7). In addition, facies identification can provide sub-classes for rock-property modeling – with larger grain size and higher energy facies having generally greater porosity and permeability.

Investigations of story thickness, stratification types and rock properties in single-story and multi-story channels have provided guidelines for populating detailed reservoir models for performance prediction. In general multi-story and single story channel sequences have similar facies – with the significant exception that channel lags are very rare in single-story channels. Multi-story channels have a lesser proportion of preserved Cb and Cu facies, due to erosion and amalgamation. Porosity and permeability within facies classes are similar between single and multi-story channels.

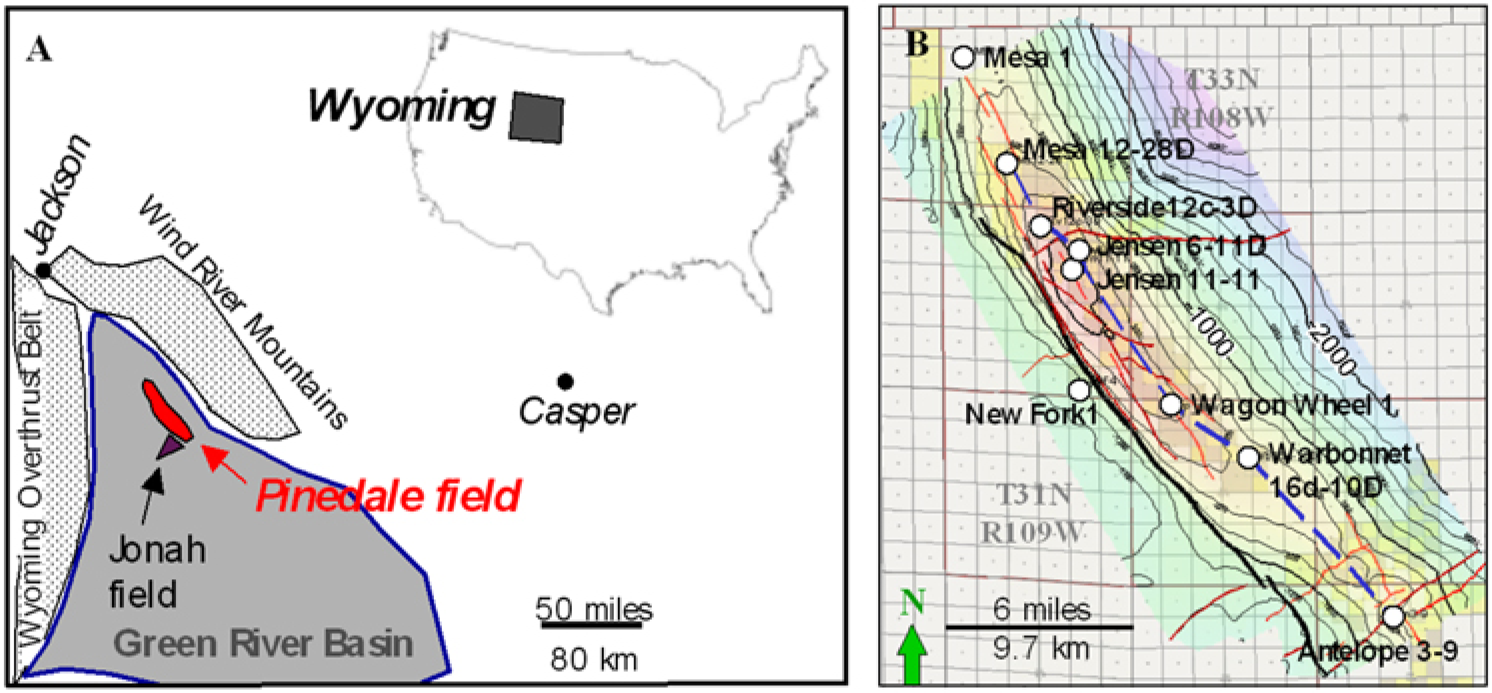

Figure 1. (A) Location map of Pinedale field, Wyoming, United States. (B) Structure contour map on Gamma Ray marker covering southern 2/3 of the field, created from 3D seismic interpretations by A. Robertson and R. Whale (contour interval 200 ft). Locations of wells mentioned in the text or figures are shown. Heavy black lines indicate structure-bounding reverse faults. Red lines indicate smaller faults. Blue dashed line indicates well log cross section shown in Figure 4.

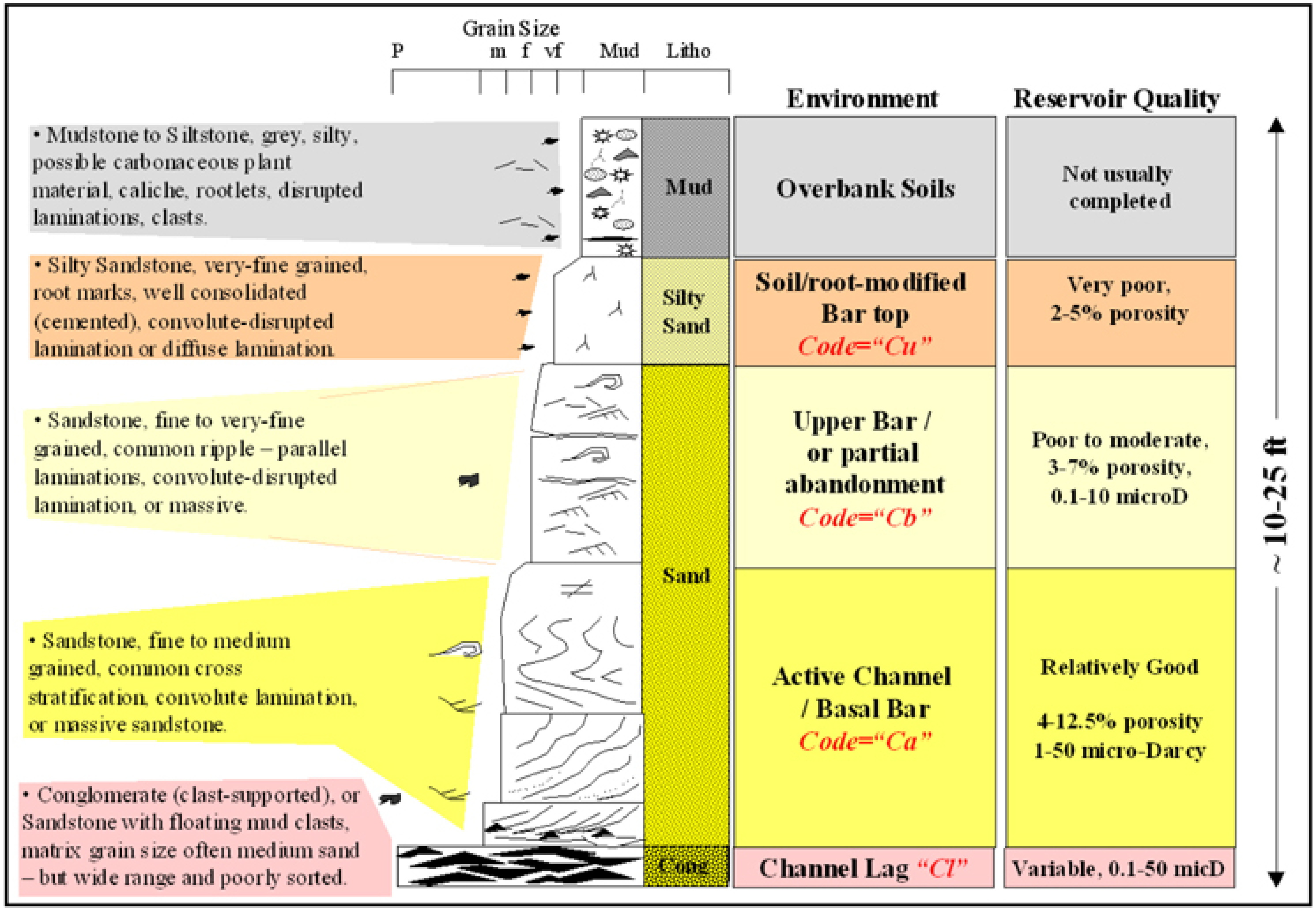

Figure 2. Characteristics of a typical fining-up sequence common to Pinedale fluvial channels. The thickness of each facies may vary or the facies may be absent in individual cases.

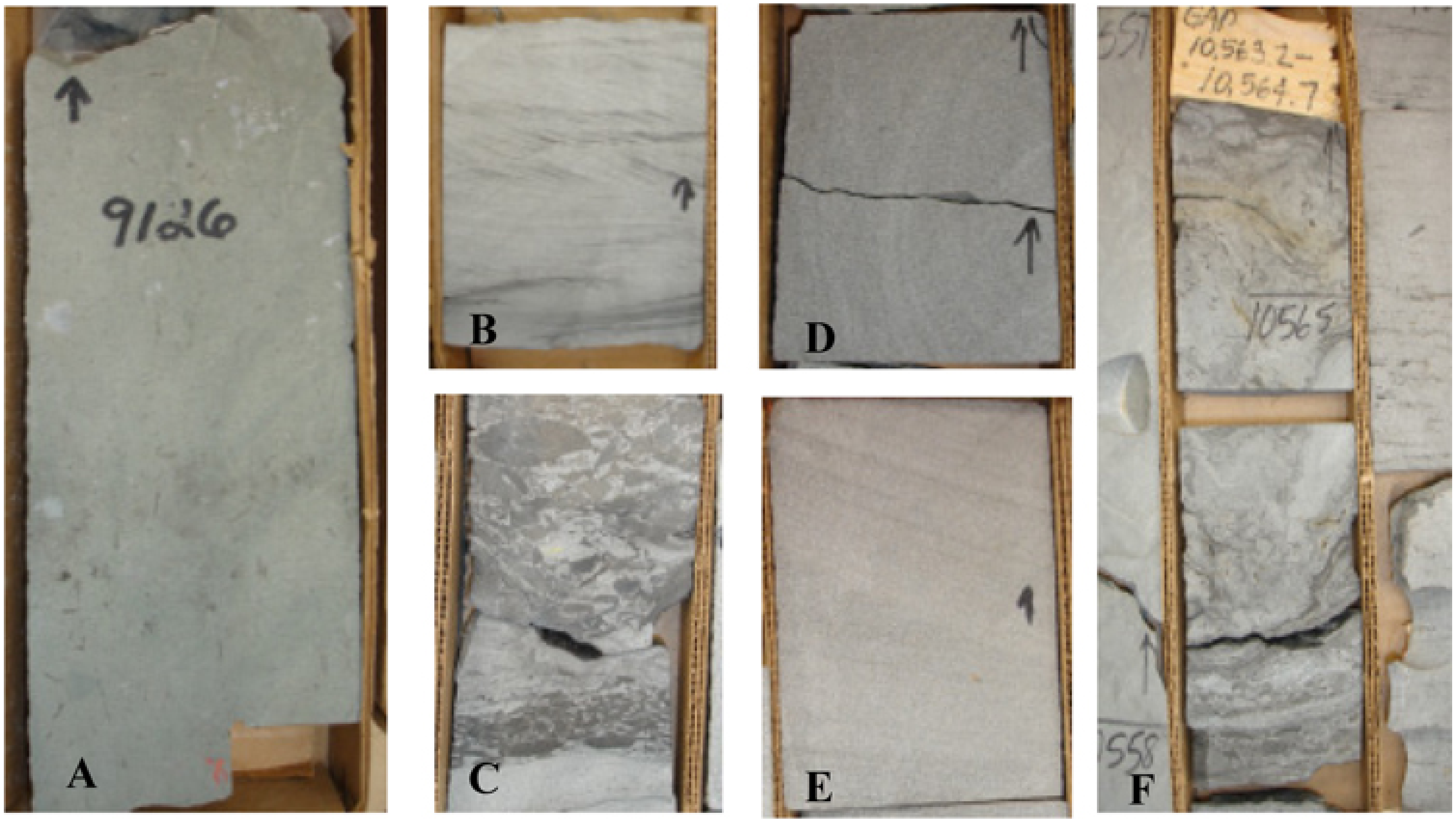

Figure 3. Core slab examples of sandy channel facies from the Mesa 1 well. Each slab is approximately 3 inches (7.5 cm) in width. (A) Very fine sandstone containing root traces and caliche nodules, interpreted as soil-modified bar top (“Cu” facies”). (B) Very fine sandstone containing ripple lamination, interpreted as upper bar (“Cb” facies). (C) Mud clast conglomerate, interpreted as channel lag (“Cl” facies). (D) Convolute fine-grained sandstone – likely over-steepened cross stratification, interpreted as lower bar or active channel fill (“Ca” facies). (E) Trough-cross-stratified, fine-grained sandstone, interpreted as lower bar or active channel fill (“Ca” facies). (F) Contorted very-fine sandstone indicating soft sediment deformation. This feature is very common in Pinedale cores and is interpreted to occur in a number of environments, including partially abandoned channels, upper bar facies, and crevasse splays. See Shanley (2004) for additional core photos of stratification types common to Pinedale and Jonah fields.

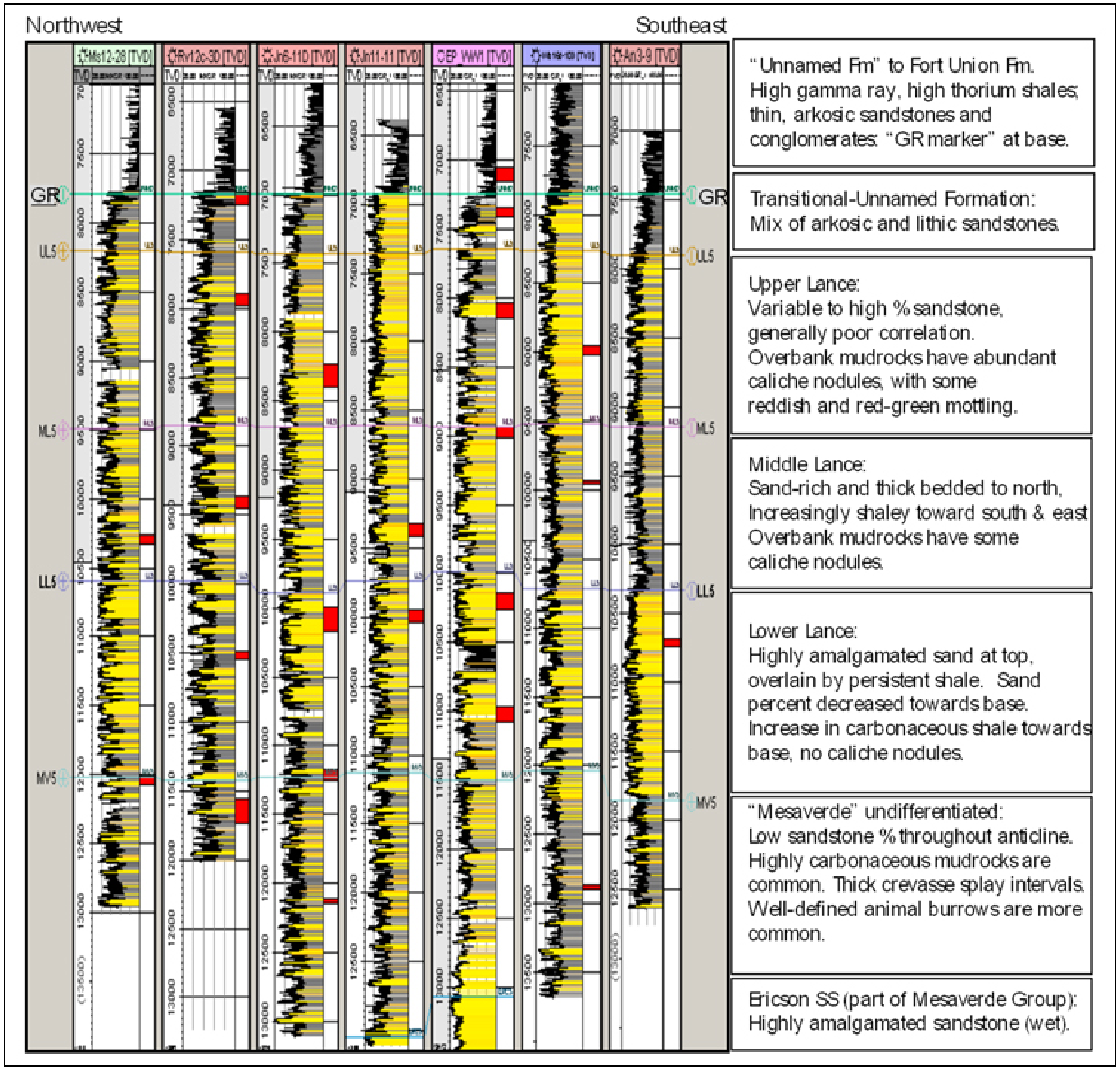

Figure 4. Well log cross section showing gamma ray logs and cored intervals (red boxes) in selected wells. Gamma logs are colored yellow when API count is <65, indicating sandstone. General stratigraphic characteristics are listed for each major interval. Interval names are not formalized in the field – this represents Shell's internal nomenclature. The definition of the "Unnamed Formation" is generally consistent with Law and Spencer (1989). Line of section is shown in Figure 1B. Well names from left to right are: Mesa 12-28D, Riverside 12c-3D, Jensen 6-11D, Jensen 11-11D, Wagon Wheel 1, Warbonnet 16d-10D, and Antelope 3-9.

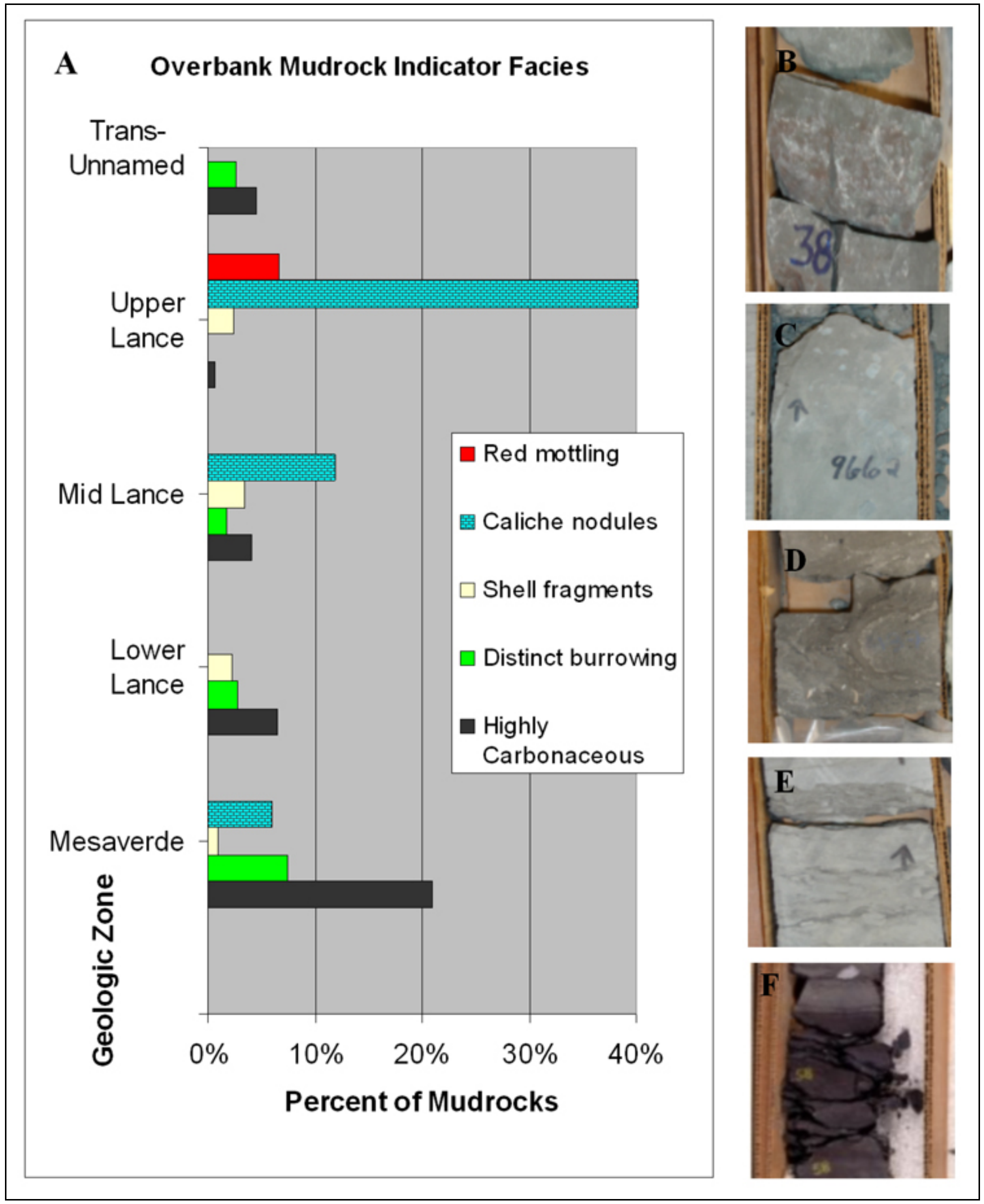

Figure 5. (A) Plot of overbank mudrock indicator facies percent by geologic zone. (B) Core photo of red-mottled mudstone, from New Fork 4 well. (C) Core photo of caliche nodules in siltstone, from Mesa 1 well. (D) Core photo of convolute mudstone with shell fragments, from Wagon Wheel well. (E) Core photo of bioturbated, silty sandstone from Wagon Wheel well. (F) Core photo of highly carbonaceous mudstone from Riverside 12c-3D well. Core slabs B-E are approximately 3 inches (7.5 cm) in width; core slab F is approximately 1.5 inches (3.5 cm) in width.

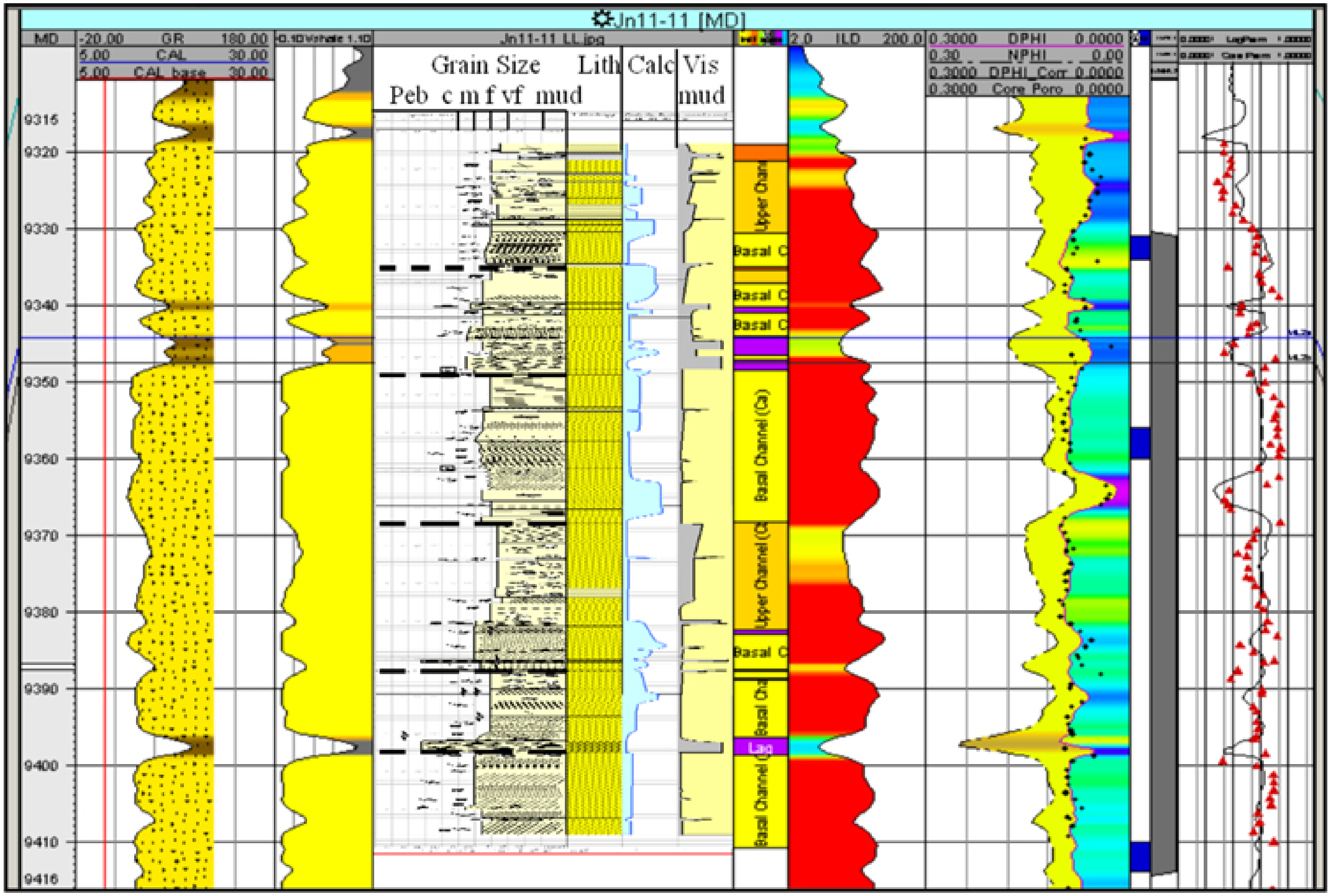

Figure 6. Log and core plot of a multi-story channel sequence in the Jensen 11-11 well. Data tracks from left to right include: Measured depth (feet), Gamma ray and Caliper, Vshale (yellow < 0.4), Core grain size and stratification – dashed lines indicate storey boundaries, Core lithology, Core calcite reactivity to acid (blue increases to right), Core visible mud fraction, modeling facies class, resistivity (red > 16 ohm-m), Neutron-Density porosity with core porosity (black dots), perf zones (blue bars), Frac stage (grey bar), and Permeability (log derived from k-phi transform is black line, red triangles indicate stressed core permeability).

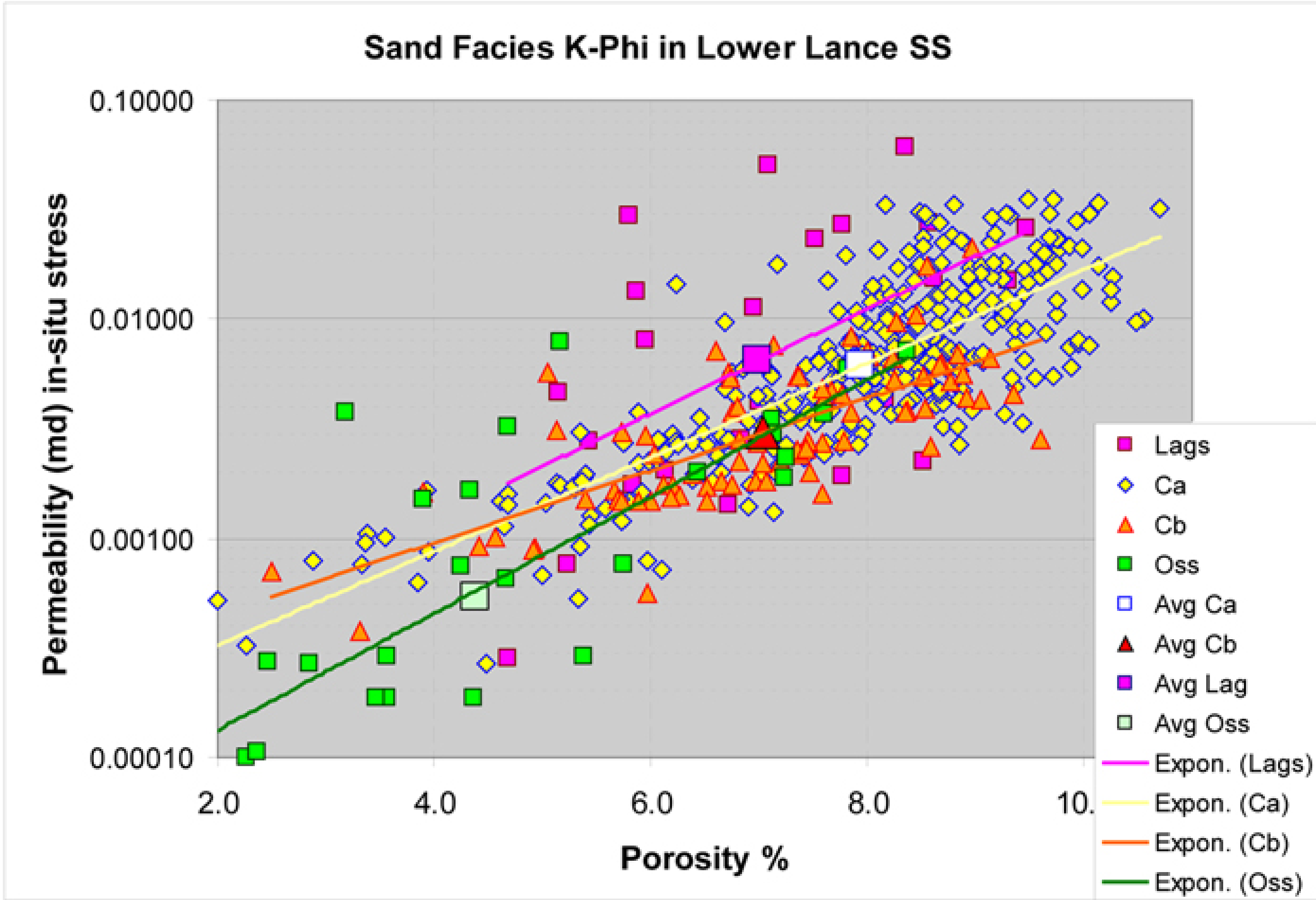

Figure 7. Permeability vs. porosity trends for reservoir lithofacies. Lags = sandy portion of mud-clast and pebble lags, Ca = basal bar or active channel, Cb = upper bar or partial abandonment, Oss = Crevasse splay sandstones.

References

Law, B.E. and C.W. Spencer, 1989, Geology of tight-gas reservoirs in the Pinedale anticline area, Wyoming, and at the multiwell experiment site, Colorado: U.S. Geological Survey Bulletin, v. 1886, 260 p.

Shanley, K.W., 2004, Fluvial reservoir description for a giant, low-permeability gas field: Jonah Field, Green River Basin, Wyoming, U.S.A., *in* J.W. Robinson and K.W. Shanley, eds., Jonah Field: A Case Study of a Tight-Gas Fluvial Reservoir: AAPG Studies in Geology 52, p. 159-182.