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Upper Cretaceous Tight Gas Sands in Wyoming Basins

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Abstract
Most gas-bearing, upper Cretaceous sandstones in the Rocky Mountain region are tight. However, porosity and permeability "sweet spots" still exist in certain lithofacies. A complete analysis, petrographically and petrophysically, is needed to better understand the reservoir properties of tight gas sands.

Introduction
The upper Cretaceous, tight, overpressured (>9,000 ft depth) sandstones in Wyoming basins contain tremendous gas reserves, such as the Almond, Frontier, and Lance sandstones in the Greater Green River Basin; the Mesaverde, Frontier, and Lance sandstones in the Wind River Basin; and the Frontier sandstone in the Bighorn Basin. Cumulative gas production through the year 2000 was 6.5 Tcf from the Frontier Formation and 2 Tcf from the Almond Formation. The Lance Formation produced 495 Bcf from 1996 to 2000. With new discoveries in the Jonah, Pinedale anticline, and Cave Gulch gas fields in the last decade, the Wyoming upper Cretaceous tight sands have proven to be good potential exploration targets for natural gas in the United States.

Samples were collected and made into thin sections from the productive, upper Cretaceous Almond, Lance, and Frontier sandstones. The Almond thin sections were selected from Washakie Basin, the Lance thin sections from the Jonah field, and the Frontier thin sections from the Bighorn Basin. These thin sections were described and point-counted, with 300 counts per thin section. Detrital composition was categorized into quartz, feldspar, and rock fragments. Porosity and permeability data were collected from the Washakie Basin for the Almond sandstones, from the Green River and Wind River basins for the Lance sandstones, and from the Wind River and Bighorn basins for the Frontier sandstones.

General Properties
The upper Cretaceous sandstones in Wyoming were sourced from the Idaho-Wyoming thrust belt, and deposited in the eastern foreland basins. Due to lithologic variations in the source areas and lack of transportation sorting, the upper Cretaceous sandstones are rich in lithic, chert, and feldspar grains. The Almond sandstones (Figure 1) contain up to 58% lithic fragments and 26% detrital feldspar grains, the Lance sandstones (Figure 2) contain up to 59% lithic fragments and 6% feldspar grains, and the Frontier sandstones (Figure 3) contain up to 48% lithic fragments and 50% feldspar grains. Chert population makes up a big proportion of the detrital grains. The Lance sandstones contain up to 43% chert grains, the Frontier sandstones contain up to 24%, and the Almond sandstone up to 6%. Matrix and authigenic clays are also significant causes of porosity and permeability reduction in these deeply buried, tight sandstones. In the analyzed samples, clay content in the Lance sandstones ranges from 10 to 25%, and in the Almond sandstones, matrix content is up to 5%. Carbonate and quartz are the major chemical cements filling intergranular pores in these sandstones. Quartz overgrowth cement and carbonate patches are commonly observed in sandstones from all three formations. With increasing burial, mechanical compaction and chemical cementation led the sandstones to become tight. Porosity in these tight sandstones is dominated by secondary porosity, which ranges from 5 to 8% and resulted from the dissolution of detrital grains and cements. Permeability is generally less than 1 md. Micropores in clays and leached detrital grains contribute only to porosity, but do not contribute significantly to permeability. Thus, in these tight sandstones, permeabilities do not correlate well with core-measured porosities (Figure 4 through Figure 6).

Sweet Spots
Exploration experience indicates that porosity and permeability "sweet spots" exist in tight gas sandstones in Wyoming. Porosity and permeability "sweet spots" have been proven to hold tremendous gas reservs and are potential targets for gas exploration (CITATION). In this study, the Almond sandstones are categorized into tide channel and shoreface lithofacies. These sandstones are fine- to very-fine-grained, sublitharenites, litharenites, feldspathic litharenite, and

lithic arkoses. Mechanical compaction and early carbonate cementation rapidly reduced porosity and permeability with burial. Dissolution of feldspar and lithic grains created micropores, but led to the precipitation of clay minerals, which enhanced porosity but not permeability. Below 9,000 ft, the Almond sandstones are tight and gas-saturated in the Washakie Basin. However, sandstones in the Almond Formation were deposited in different environments, and sandstones with different textures and detrital grain composition likely experienced different diagenetic changes during burial. Changes in the distribution of porosity and permeability in the Almond sandstones are attributable to these depositional and diagenetic factors. Comparison of porosity and permeability distribution with lithofacies, compaction, and cementation, both in outcrops and in the subsurface, reveals that the tidal channel sandstones are relatively quartz-rich and have higher permeabilities than the shoreface sandstones (Figure 7). Some of the tidal channel sandstones have porosities higher than 10% and permeabilities higher than 1 md, even below 10,000 ft depth. The tidal channel sandstones are believed to be "sweet spots" in the Almond sandstones.

Analysis of Tight Sandstones

Lance Formation cores from the Jonah #2-5 well were described for lithology, color, texture, grain size, and the depositional environments was interpreted. Petrographic features were examined using an optical microscope and SEM, clay minerals were analyzed using XRD and SEM, porosity and permeability were measured under different pressures, capillary pressure was determined by mercury injection, and water sensitivity was estimated by cation exchange capacity (CEC). The Lance sandstone in the Jonah Field was deposited in fluvial channels, and ranges in thickness from 5 to 30 ft. The thick channel is comprised of stacked single channel deposits, with siltstone or shale drapes. The sandstones are characterized by massive bedding, cross-stratification, wave-ripples, and soft deformation. The sandstones are fine- to coarse-grained litharenites. Clay content ranges from 10 to 25% and carbonate cement up to 23%. Quartz overgrowth and feldspar dissolution are common. Porosity is 3.5 to 10.5% and permeability, 0.001 to 1 md under ambient conditions. Permeability in these tight sandstones is very sensitive to confining pressure; its value can decrease up to 92% if confining pressure increases from 800 psi to 4000 psi (Figure 8). The CEC of the Lance sandstones was determined by clay minerals and their content. The measured CEC values can be roughly attributed to the clay minerals determined from XRD in each of the samples.

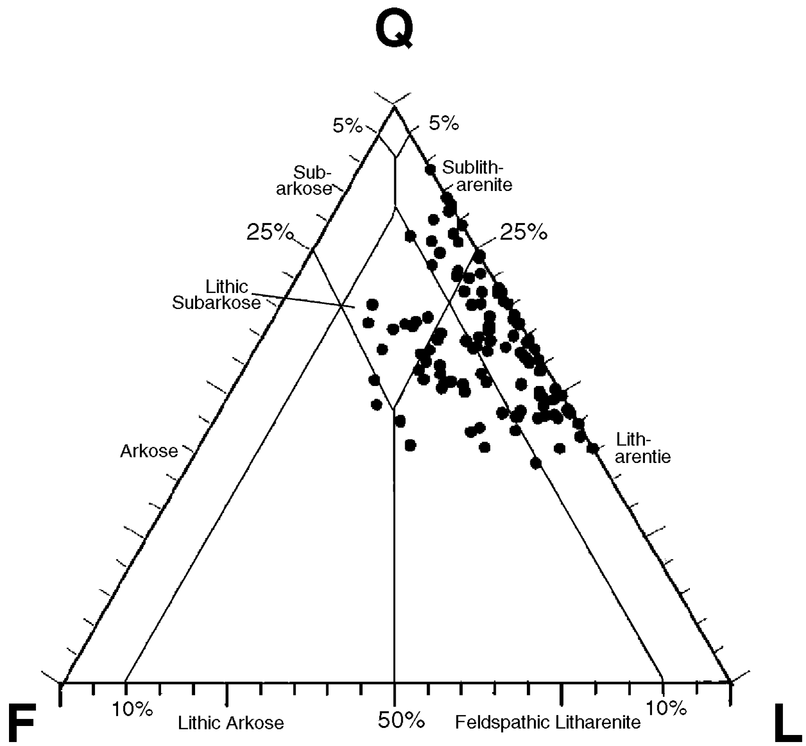

Figure 1. Almond sandstones from the Washakie Basin.

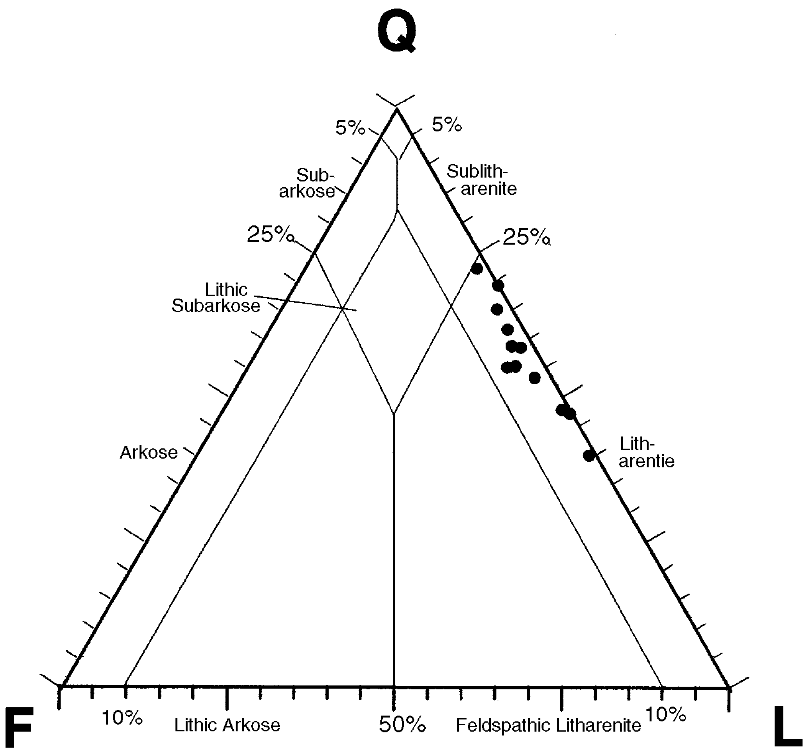

Figure 2. Lance sandstones in the Jonah field.

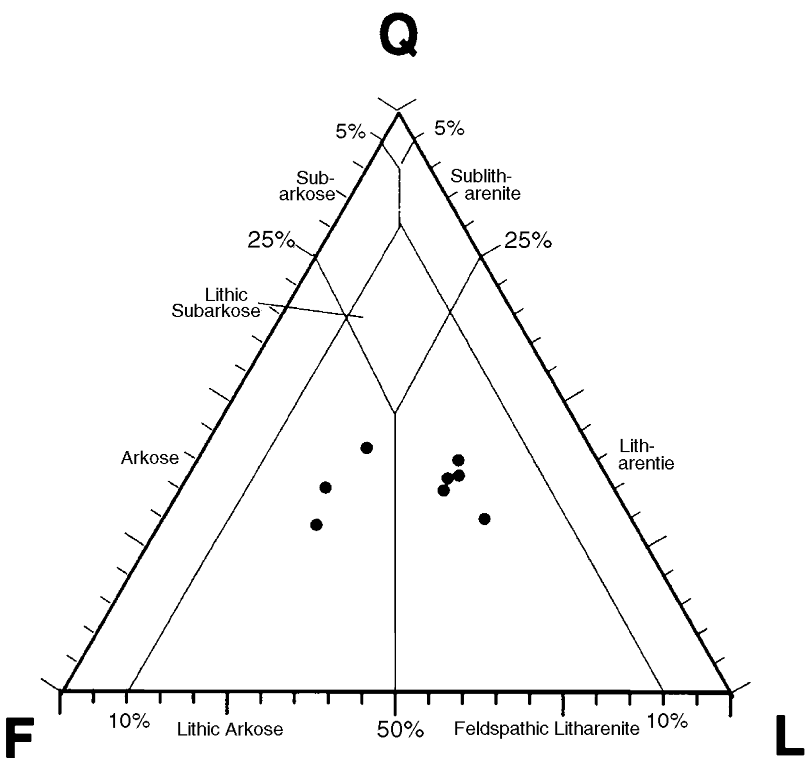

Figure 3. Frontier sandstones in the Bighorn Basin.

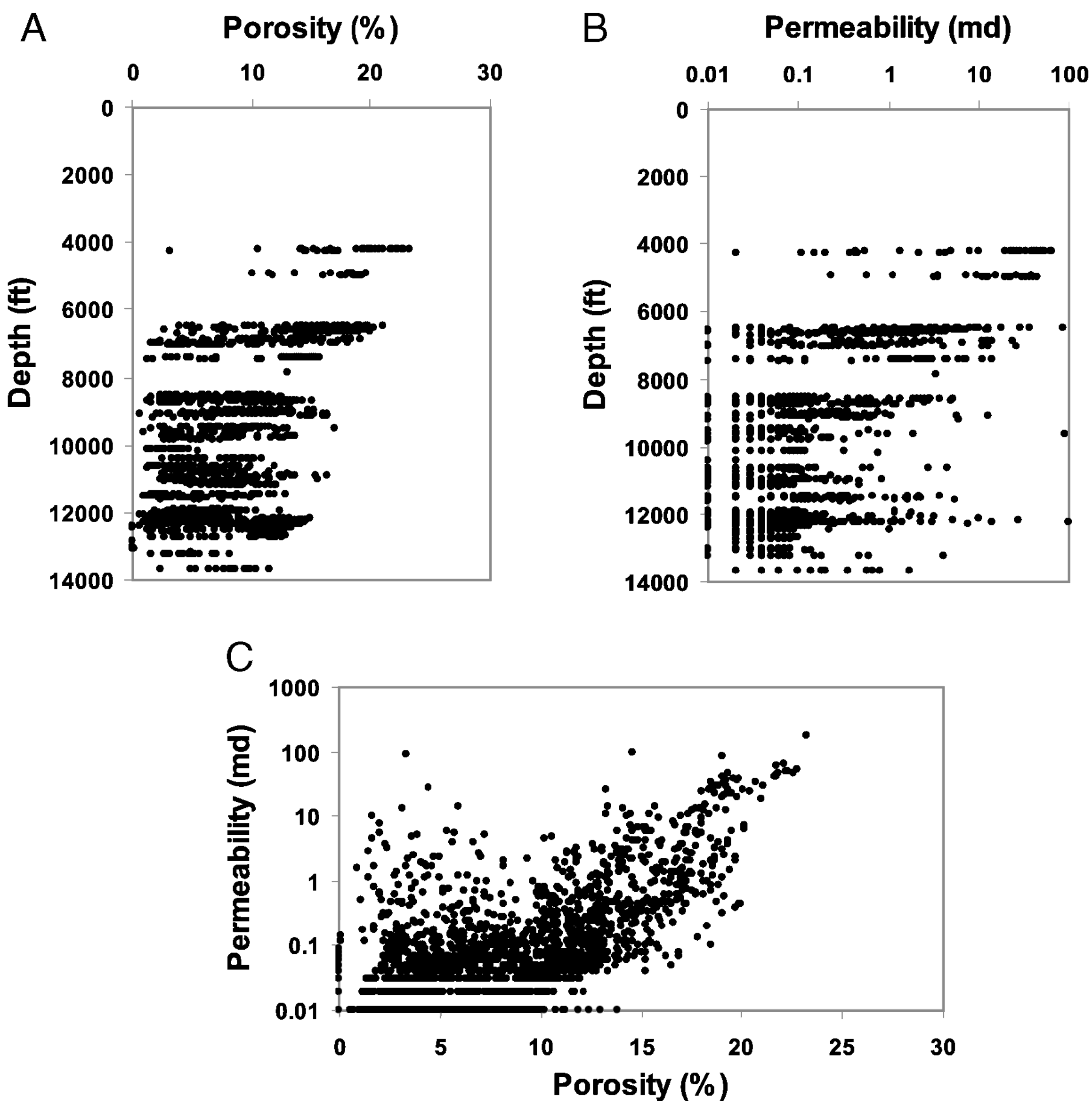

Figure 4. Almond sandstones from the Washakie Basin.

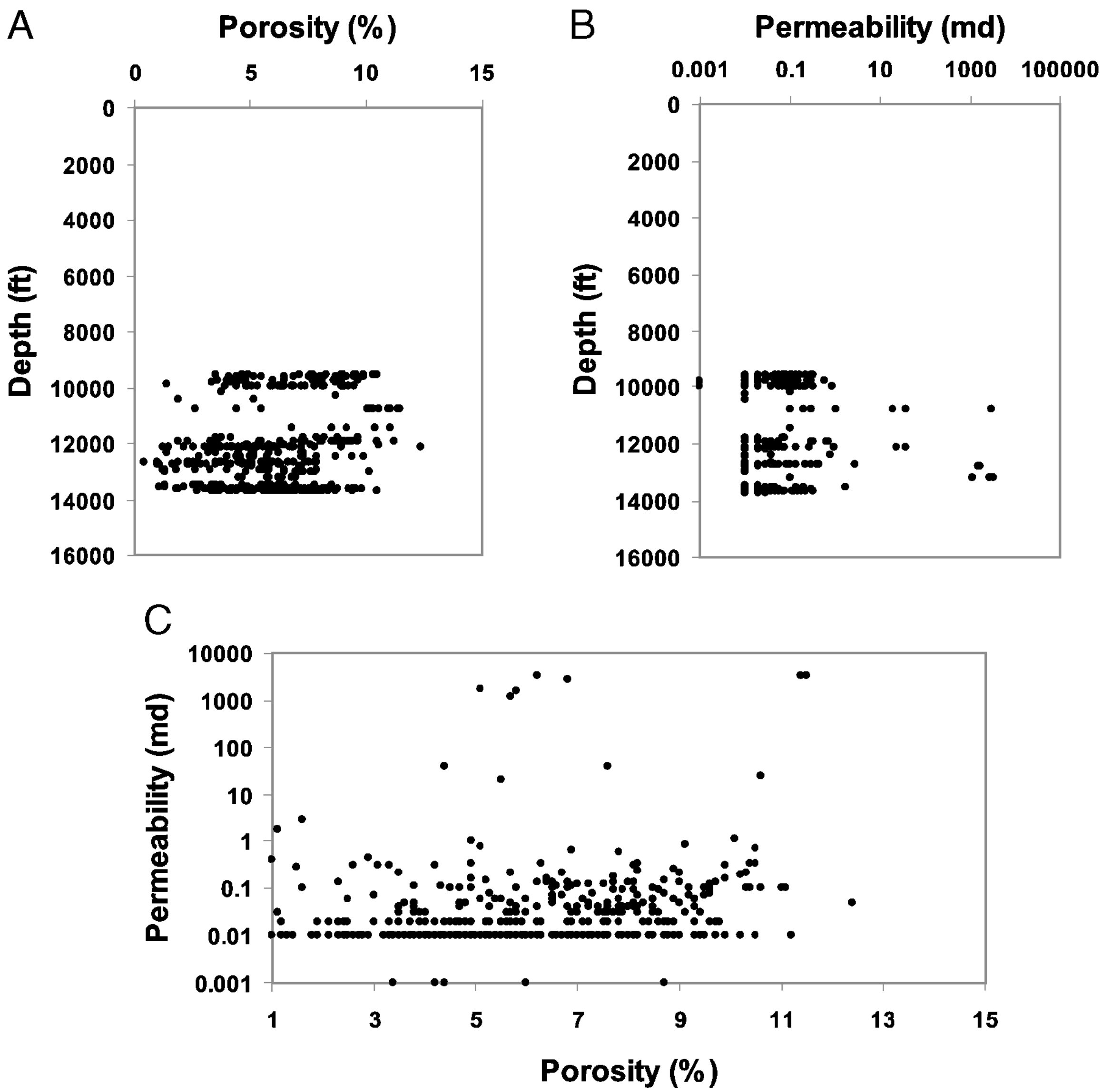

Figure 5. Lance sandstones from the Greater Green River and Wind River basins.

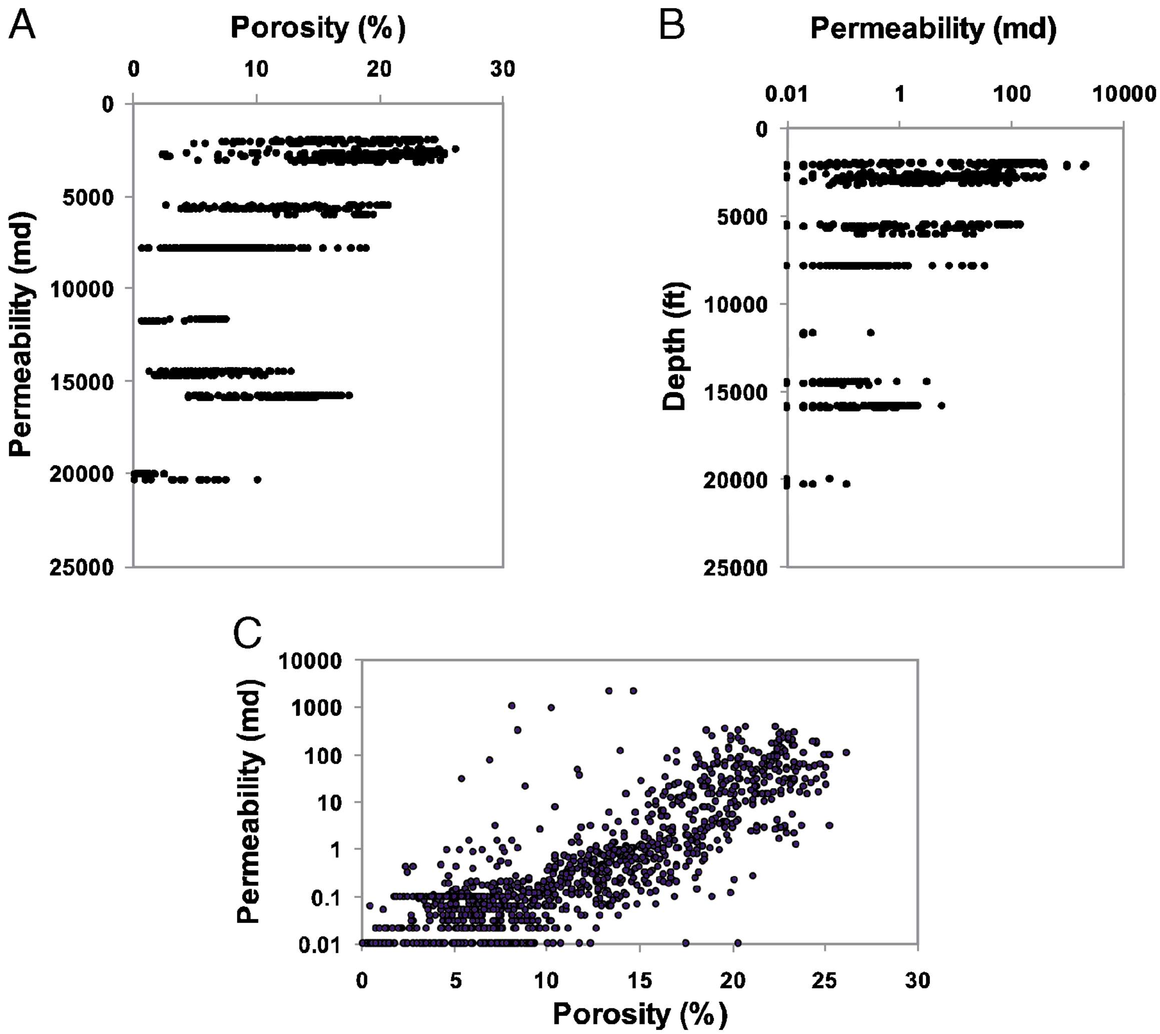

Figure 6. Frontier sandstones from Wind River and Bighorn basins.

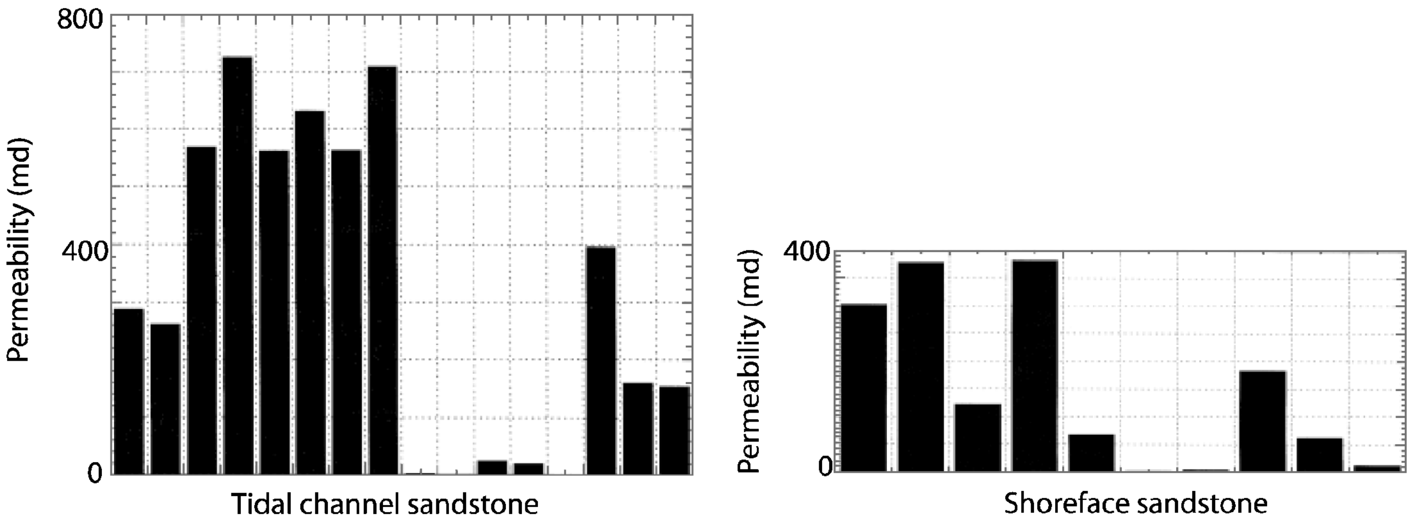

Figure 7. Comparison of permeability in subsurface tidal channel and shoreface Almond sandstones.

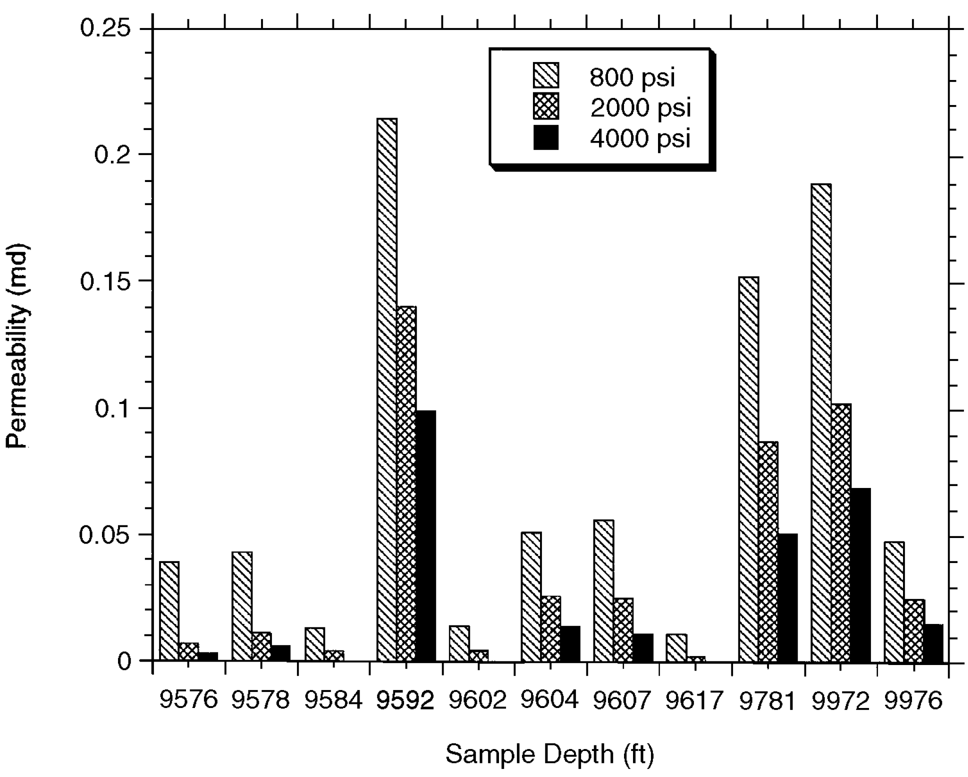

Figure 8. Effect of confining pressure to permeability in tight Lance sandstones.