Shale-Gas Production and Sequence Stratigraphy: What Makes the Best Part of the Best Plays?

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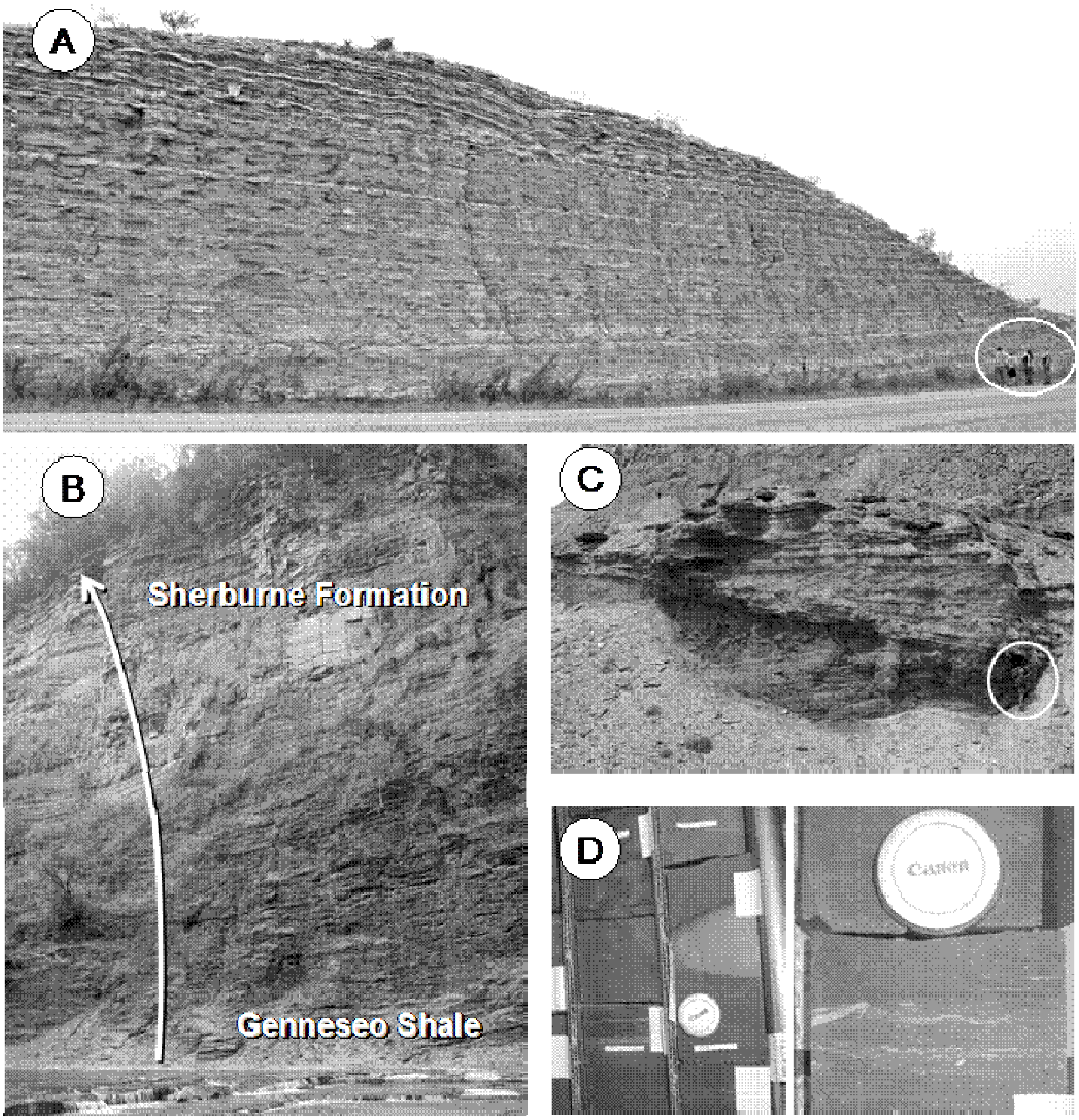
Stratigraphic and sedimentologic analyses of productive and non-productive “shale-gas” units (e.g., Haynesville/Bossier, Barnett, Eagle Ford, Marcellus, Woodford, Muskwa, Lewis, Mancos) demonstrate that the best gas production is from thermally mature, pelagic-rich strata that can be assigned to the transgressive systems tract and condensed section (TST/CS). These rocks are relatively enriched in marine organic matter and biogenic silica and/or carbonate. They are often referred to as “black shales”, although clay minerals can form 20% or less of the rock. (The term “mudstone” is preferred here to describe the lithology, although the term “shale” has historical use for defining stratigraphic units; e.g., “Mancos Shale”). The high TOC content made these strata potential source rocks, and recrystallization of the silica and/or carbonate produced “brittle” rock that is suitable for hydraulic fracture stimulations. Furthermore, these predominantly pelagic deposits commonly drape underlying paleobathymetry, and have thin (< 10 m thick) stratigraphic units (?parasequences) that can be correlated over several to many 10s of kilometers (Figure 1A). Rock properties (e.g., porosity, Poisson’s Ratio, Young’s Modulus) are therefore unlikely to change significantly over the length of a typical horizontal completion (~ 1 km) in the TST/CS, unless structural complications (i.e. faults, fractures and, possibly, associated diagenesis) are present.

The lithologic and stratigraphic characteristics of the TST/CS strata differ considerably from the, usually, overlying progradational mudstones of the highstand systems tract (HST) and, locally, the lowstand systems tract (LST). The latter are characterized by higher clay contents and more detrital silicate/carbonate as silt or coarser grain sizes. The clay content generally makes these shales less brittle than the TST/CS units, although the coarse-grained detrital component (typically present as “event beds” such as turbidites or shelfal storm beds) may be fractured especially if the beds are highly cemented. These HST mudstones have lower TOC contents than the TST/CS mudstones, and the organic matter is relatively enriched in terrestrial (Type III) constituents. These strata tend to be more heterolithic than the TST/CS shales, and are often referred to as “grey shales” (Figure 1B). Furthermore, the HST strata may be arranged into submarine failure complexes (e.g., deep-water turbidite fans, prodelta failure complexes; Figure 1C), prodelta lobes or other stratigraphic features that can show rapid lateral variations in lithology and thickness. These characteristics generally make these HST strata less amenable to development using horizontal wells, although “tight-oil” production (using horizontal wells) is currently being established from heterolithic (marine sandstones and mudstones), progradational strata of the Upper Cretaceous Cardium Formation (Alberta) that can be described as HST/LST deposits.

Although the descriptions and interpretations presented above have general applicability (i.e. they are the “simple case”), these concepts commonly need to be modified to account for the wide variability in depositional setting, and geologic age, represented by gas-productive mudstones. For example, pelagic carbonate-secreting nano- and micro fossils (coccoliths, calcareous foraminifers) are absent prior to the late Mesozoic, and so Paleozoic pelagic deposits (e.g., Upper Devonian – Lower Mississippian Woodford) are composed primarily of siliceous microfossils (radiolarians). Log- or XRD-derived mineralogic analyses are insufficient for reconstructing depositional processes or physical property predictions because minerals such as calcite and quartz can be authigenic (e.g., concretions), biogenic (tests or shells of organisms), or detrital (“event beds”) as illustrated in Figure 1D. Another complication is that transgressions and regressions of different durations and magnitudes can be superimposed (e.g., 3rd Order cycles with superimposed 4th Order cycles, perhaps described as parasequences and parasequence sets). This stacked cyclicity can make recognition of large-scale trends difficult to identify (sample spacing needs to be carefully defined) or cause clastic dilution of transgressive deposits that might otherwise have made for a more successful shale-gas play. Finally, mudstones deposited long distances from a prograding shoreline, essentially cut off from clastic detritus (at least during transgression and peak transgression), can respond to changes in sea level, thermohaline circulation, tectonic movements, etc. in ways that are not amenable to conventional sequence stratigraphic analyses. For these and other reasons, detailed stratigraphic analyses (e.g., stratigraphic analyses using closely spaced wells), data integration (core, logs, biostratigraphy, chemostratigraphy, etc.), and reasoning from first principles (e.g., how could changes in oceanic currents affect upwelling, nutrient supply and paleo-productivity?) are typically needed to construct working hypotheses that explain the available data and make predictions of economically significant properties away from existing well control.

Figure 1 (next page). A) Pelagic-dominated clean and organic-rich limestones of the Cretaceous Boquillas Formation (outcrop equivalent of the Eagle Ford) near Del Rio, Texas show excellent stratigraphic continuity. Some individual beds within the Boquillas can be traced between roadside outcrops for at least several miles. People, circled at bottom right, for scale. B) Outcrop exposure of Devonian strata in New York showing an upward transition from “black shale” of the Geneseo (TST/CS) to “grey shale” (and sandstone) of the Sherburne Formation (HST). C) A small sandstone-filled channel body from a base-of-slope position (probable small submarine failure complex) in HST mudstones of the Cretaceous Mancos Shale, Utah. Although not always this abrupt, lateral lithologic variability is typically more pronounced in HST and LST mudstone units than in TST/CS mudstones. D) Two types of carbonate in the Barnett Shale. At left is a carbonate concretion in “black shale”. At right is a shell bed that could be interpreted as either a density current deposit or an in situ bioherm. Although some carbonate beds in the Barnett are clearly density current deposits (e.g., erosive bases, graded beds), the origin of other bioclastic layers (like this) is more enigmatic.


A
B
Sherburne Formation
Genneseo Shale
C
D
Canon