Sequence Stratigraphy as Expressed by Shale Source Rock and Reservoir Characteristics – Examples from the Devonian Succession, Appalachian Basin*

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Abstract

Most shale gas reservoir properties reflect a history of base-level fluctuations that can be cast in terms of a predictive sequence stratigraphic framework. Our approach to the sequence stratigraphy of the Devonian gas shale succession of the Appalachian Basin is grounded in the transgressive-regressive (T-R) sequence concept. A single T-R sequence comprises transgressive systems tract (TST) deposits overlain by a regressive systems tract (RST) succession, the contact being a maximum flooding surface (MFS); the sequence is bounded on top and bottom by maximum regressive surfaces (MRS) or equivalent ravinement surface. Early results of a multi-faceted investigation of the Devonian shale succession of the Appalachian Basin reveal that such parameters as mineralogy, microfabric, TOC, and source rock quality vary predictably within the T-R sequence stratigraphic framework. A general increase in silica, much of it diagenetic, and reduction of clay upward through the TST reflects the rapid landward migration of the shoreline. Further, spectral gamma-ray analysis reveals generally increasing levels of authigenic uranium through the TST. TST deposits are commonly pyritiferous and organic-rich, both parameters attaining maximum values close to the MFS. Increasing thermal maturity of these deposits is accompanied by increasing porosity, principally nanoporosity. Bacterial reworking of transgressive organic-rich sediment, especially proximal to maximum base level, appears to have resulted in some degree of vitrinite suppression. Accumulation of RST deposits is recorded by increasing clay and detrital quartz and concomitant dilution of the organic flux. The result is higher bound water contents and a pervasive planar clay-grain microfabric disrupted only by occasional discrete detrital quartz lamina or isolated grains. Base-level minimum is defined by minimal TOC and local carbonate horizons. The predictive capabilities inherent to sequence stratigraphy make it especially applicable to exploration programs of seemingly homogenous shale successions.

References


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...sedimentologic/stratigraphic attributes related to base level fluctuations and manifested by systems tract variations include a variety of parameters critical to source rock and reservoir properties...

...organic carbon content ... ...mineralogy ...
...grain size ... ...microfabric...
...bedform geometry... ...diagenetic components...

...porosity, permeability, brittleness...
... transgressive-regressive sequence ...
wave-worked arenaceous limestone unconformably overlying marine mudstone (Moscow Member) ...
Genundewa Limestone

Moscow Member

West River Member

increasing TOC; diminished wave activity

deepening up trend
Middlesex Shale

West River Shale

reworked pyrite interval

50 cm
reworked pyrite interval
Cashaqua Shale

Middlesex Shale

West River Shale

Genundewa Limestone

Moscow Shale

RST

shallowing up trend

deepening up trend

sequence boundary... unconformable shoreline ravinement
...recrystallized silica...dissolution of biogenic (opaline silica) particles...
...greater abundance of clay in RST deposits fosters development of an anisotropic microfabric...
...bioturbation (?)...
...TST... increasing base level and related landward shift of depositional environments leads to 1) reduced clastic flux (clay and detrital quartz) and 2) increased abundance (concentration) of bioclastic particles (Si) and eolian (Si, Ti) detritus...

...elevated (diagenetic) quartz and reduced clay >>>>> enhanced brittleness...
TOC vs. quartz

TOC vs. quartz

TOC (wt%) vs. QUARTZ

R = 0.66
$%R_o > 1.4$
%Ro = 0.6-0.74%

$r^2 = 0.35$

gray shale (organic-lean)
Hanover Shale, Cashaqua Shale

black shale
Dunkirk Shale, Rhinestreet Shale
%Ro = 0.64%

ductile organic particles...
$r^2 = 0.77$

%Ro = 2.3%

development of generation induced nanoporosity...
from Slatt and O'Brien (in press), provided by M. Zheng
%R_0 > 1.4

conversion-related porosity

initial porosity

total organic carbon (wt %)

total porosity (%)
...**TST**... depending on thermal stress (%Ro), porosity and permeability may increase from the base to top of the TST (base of the RST) in response to increasing TOC...
strong correlation of pyrite and TOC....MFS/condensed interval
from Slatt and O'Brien (in press), provided by M. Zheng
TST and condensed section deposits...

- abundant quartz; reduced clay – increased brittleness
- abundant TOC and pyrite – diminished brittleness (but potentially higher porosity at higher thermal stress levels)
Marcellus Shale, northern central West Virginia

580 ppm; “average” shale (Wedepohl, 1971)
Marcellus Shale, northern West Virginia

580 ppm
Marcellus Shale, eastern New York

enhanced paleoproductivity perhaps during a period of increasingly oxic conditions (elevated Mn)
elevated chloride and strontium levels
salt described from Marcellus cores; Blauch et al., 2009
Marcellus Shale, northern central West Virginia

enhanced Cl and Sr ... associated with TST deposits at the base of the Marcellus ... salinity excursions...
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