# Potential Sequence Stratigraphic Controls on Frac Design: An Integrated 3-D Seismic Reservoir Characterization Using P-Wave Impedance Inversion Data from Marcellus Shale, Pennsylvania

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Intelligent geosteering of horizontal wells coupled with numerous engineering advances in well completion techniques has helped turn hitherto “unconventional” shale gas exploration into a significant global conventional resource play for natural gas. Total gas-in-place in the North American Devonian Marcellus Shale alone is estimated at nearly 600 TCF. Because shale plays tend to be primarily land-driven, pre-stack and hereditary post-stack time-migrated seismic attribute data may actually help bridge the gap between wellbore engineering data and mapped reservoir properties. Specifically, frac design, prediction of future frac success, and delineation of “sweet spots” for the purpose of highgrading acreage positions will in all likelihood have to come from 3-D seismic data. Inverting spectrally enhanced seismic amplitude data for static YOUNG’s modulus shows exactly such promise. In addition, post-stack time-migrated 3-D P-Wave impedance data permit application of sequence stratigraphic concepts and analysis to a dataset from the southern portion of the Marcellus Shale play. Specifically, systematic reflection termination patterns help define three major depositional systems tracts within this shale sequence: onlap defines an early transgressive phase (i.); downlap delineates a maximum flooding surface forming the base of the regressive section (phases ii .& iii.). Offlap heralds a change in the geometry of progradation from convex-up, sigmoidal clinoforms to concave-up reflections (= tectonic quiescence). A minor transgressive incursion appears at the top of the section. This formal stratigraphic division compares favorably to core, rock physics and engineering knowledge that holds that the Marcellus Shale is segregated into a brittle upper and a ductile lower member. Steeply increasing $V_{CLAY}$ content within the basal Marcellus section is interpreted to coincide with a deepening of the basin (possibly due to thrust-front loading). Additionally, this sequence stratigraphic analysis divides the upper Marcellus in this region into two discrete phases of late-stage basin-filling. We interpret different volume percentages of constituent mineral assemblages (“brittleness”) associated with each depositional systems tract to control values of YOUNG’s modulus by virtue of variant average bulk and shear moduli.

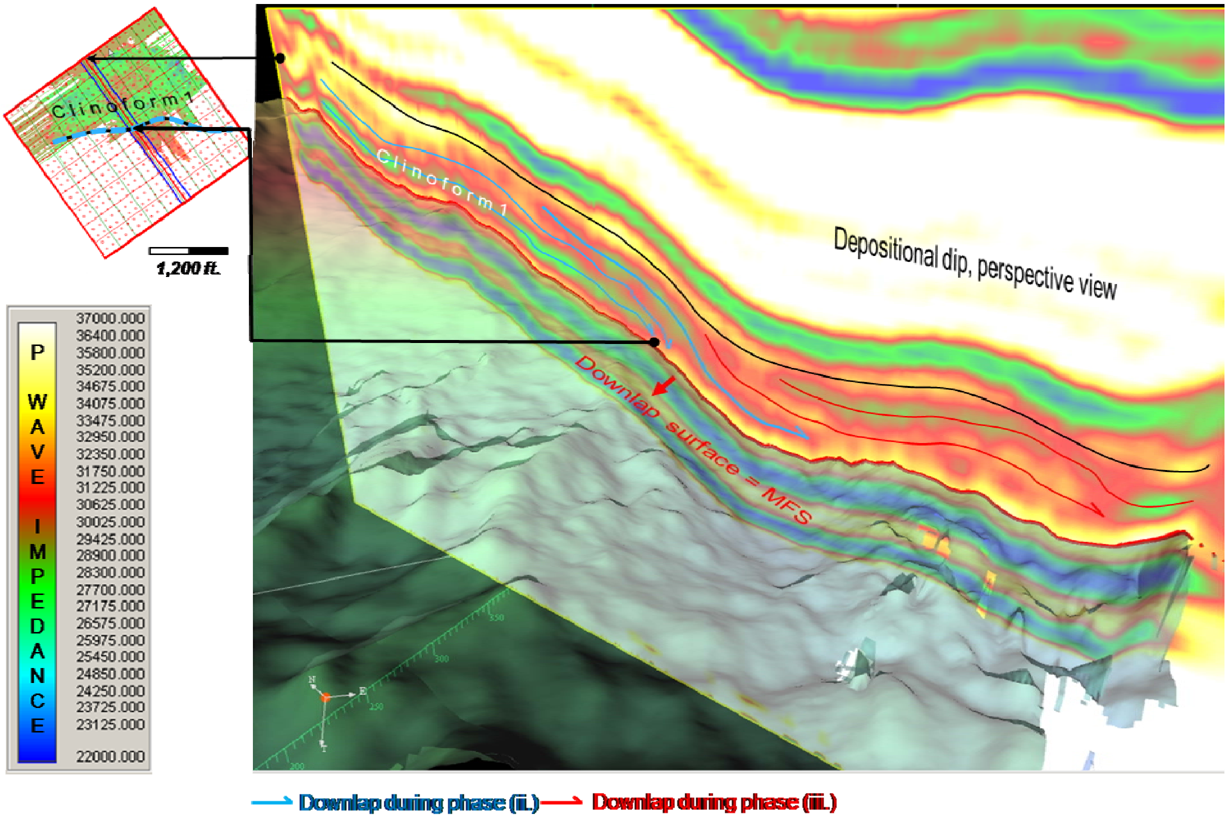


***Figure 1. Sequence Stratigraphic Line Drawing Interpretation Of P-Wave Impedance Seismic Section (Perspective View, Depositional Dip).*** *Three major pulses of MARCELLUS basin-filling phases can be identified: (1.) an early transgressive cycle, (2.) a progradational cycle, and (3.) a younger offlapping cycle that only covers the southern half of the survey. Note change in clinform geometry from convex-up during sigmoidla prgradation to convex-down during the tectonic offlap phase. A minor transgressive event appears to occur at the top of the section.*

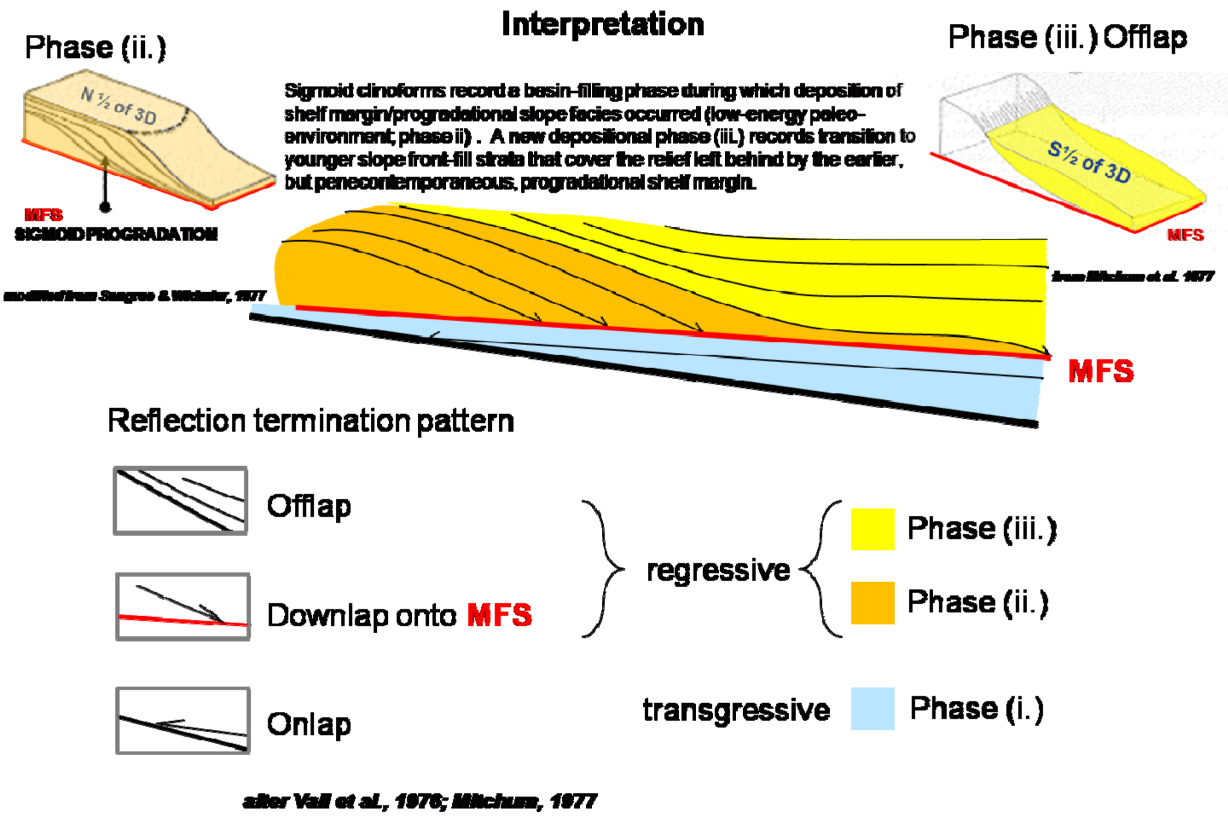


***Figure 2. Sequence Stratigraphic Line Drawing.*** *Recognition of systematic reflection termination patterns helps define three major depositional systems tracts within this shale succession:* ***onlap*** *defines an early transgressive phase (i.);* ***downlap*** *delineates a maximum flooding surface forming the base of the regressive section (phases ii .& iii.).* ***Offlap*** *heralds a change in the geometry of progradation from convex-up, sigmoidal clinoforms to concave-up reflections (= tectonic quiescence). A volumetrically less significant, minor transgressive section at the top is not shown.*