PS Integration of Sequence Stratigraphy, Petrophysical and Geomechanical Analysis for Planning and Design of Shale Gas Reservoir Stimulation*

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Abstract

Sequence stratigraphic principles provide a means to interpret the geological framework and likelihood of finding hydrocarbon-bearing rocks. These principles can be used to characterize clay mineral and silica/carbonate rich (i.e. ductile and brittle) units in shale gas reservoirs based on gamma ray stacking patterns and/or seismic data. This provides a means of predicting the reservoir response to fluid injection, variability of reservoir petrophysical and geomechanical properties (e.g. rock strength, Fracture toughness, Young's modulus, Poisson's ratio) at sequence and parasequence scales as well as better interpretation of microseismic response during stimulation treatment. Conversely, petrophysical evaluations can aid in identifying sequence boundaries and flooding surfaces, which gives rise to a succession of brittle-ductile units at parasequence scales. We apply this relationship to characterize stratigraphic positions of brittle-ductile units in the Early Permian Roseneath and Murteree shale formations of South Australia using gamma ray logs calibrated with core geomechanical tests. Since hydrocarbon migration paths in shale reservoirs tend to be short, productive zones can be restricted to a stratigraphic interval. Thus, conclusion of this study is significant to better understand shale gas reservoir characterization and identification of stratigraphic intervals susceptible to fracturing. This knowledge can be used to plan stimulation treatment that has the potential to reduce cost and optimize production.

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ABSTRACT

Sequence stratigraphic principles provide a means to interpret the geological framework and likelihood of finding hydrocarbon-bearing rocks. These principles can be used to characterize clay-mineral and silica/carbonate rich (i.e. ductile and brittle) units in shale gas reservoirs based on gamma ray stacking patterns and/or seismic data. This provides a means of predicting the reservoir response to fluid injection, variability of reservoir petrophysical and geomechanical properties (e.g. rock strength, Young's modulus, Poisson's ratio) at sequence and parasequence scales as well as better interpretation of microseismic response during stimulation treatment. Conversely, petrophysical evaluations can aid in identifying sequence boundaries and flooding surfaces. We apply this relationship to characterize stratigraphic positions of brittle-ductile units in the Early Permian Roseneath and Murteree shale formations of South Australia. Since hydrocarbon migration paths in shale reservoirs tend to be short, productive zones can be restricted to a stratigraphic interval. Thus, conclusion of this study is significant to better understand shale reservoir characterization and identification of stratigraphic intervals susceptible to fracturing.

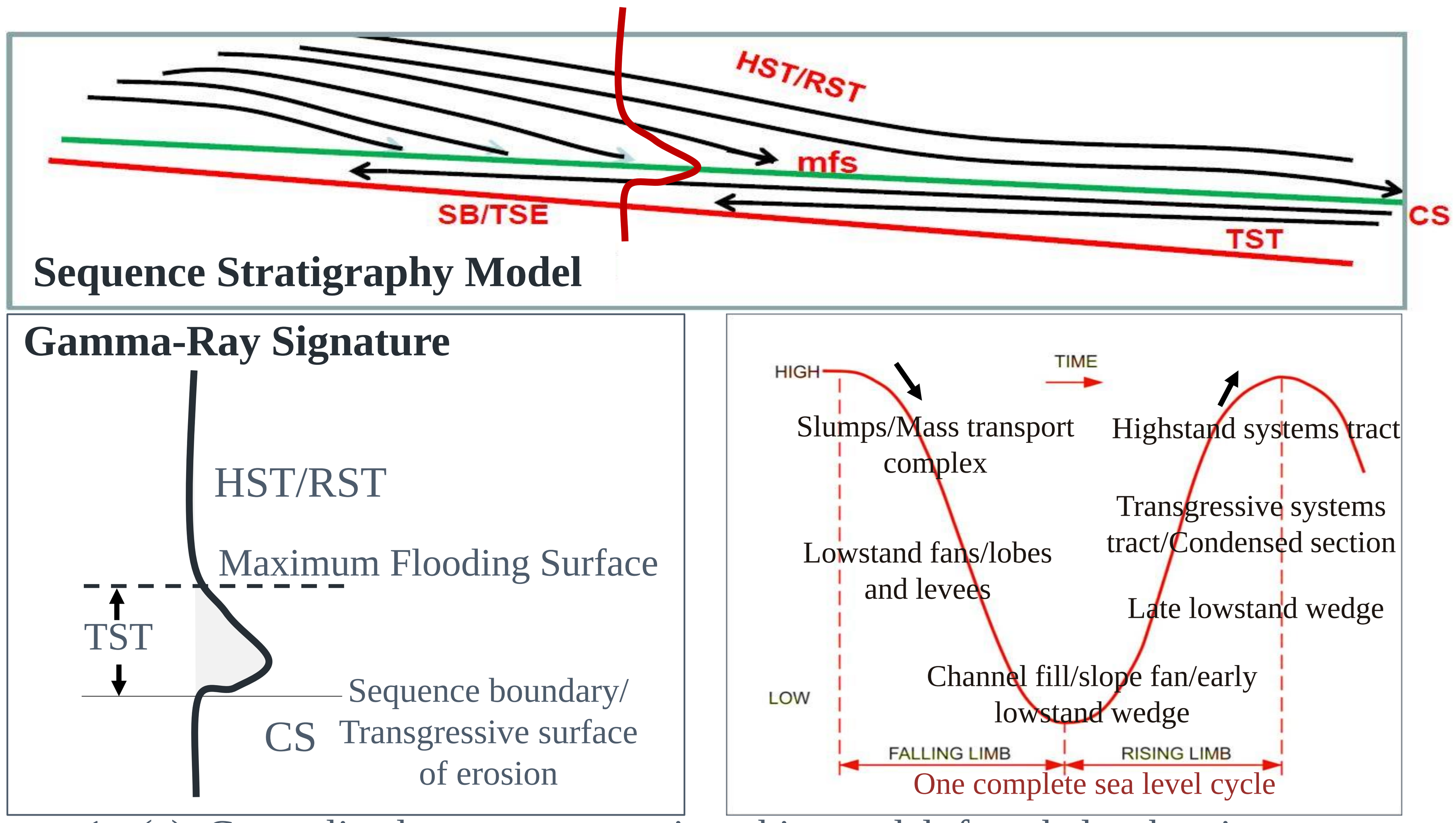


Figure 1: (a) Generalized sequence stratigraphic model for shale showing sequence boundary overlain by onlapping transgressive systems tract (TST), capped by condensed section (CS) and maximum flooding surface (mfs), with downlapping highstand/regressive systems tract (HST/RST). (b) Gamma ray signature showing high gamma ray TST/CS and lower gamma ray HST/RST. (c) Simplified sea-level stages (Modified from Slatt, 2006; Slatt & Abousleiman, 2011).

SEQUENCE STRATIGRAPHY

Sequence stratigraphic is based on the premise that through geologic time, oceans have risen and fallen in a cyclic manner. As a result, strata are deposited in a predictable manner. Most shale resources were deposited as 3rd order sequences superimposed in a 2nd order sequence represented as a composite eustatic curve.

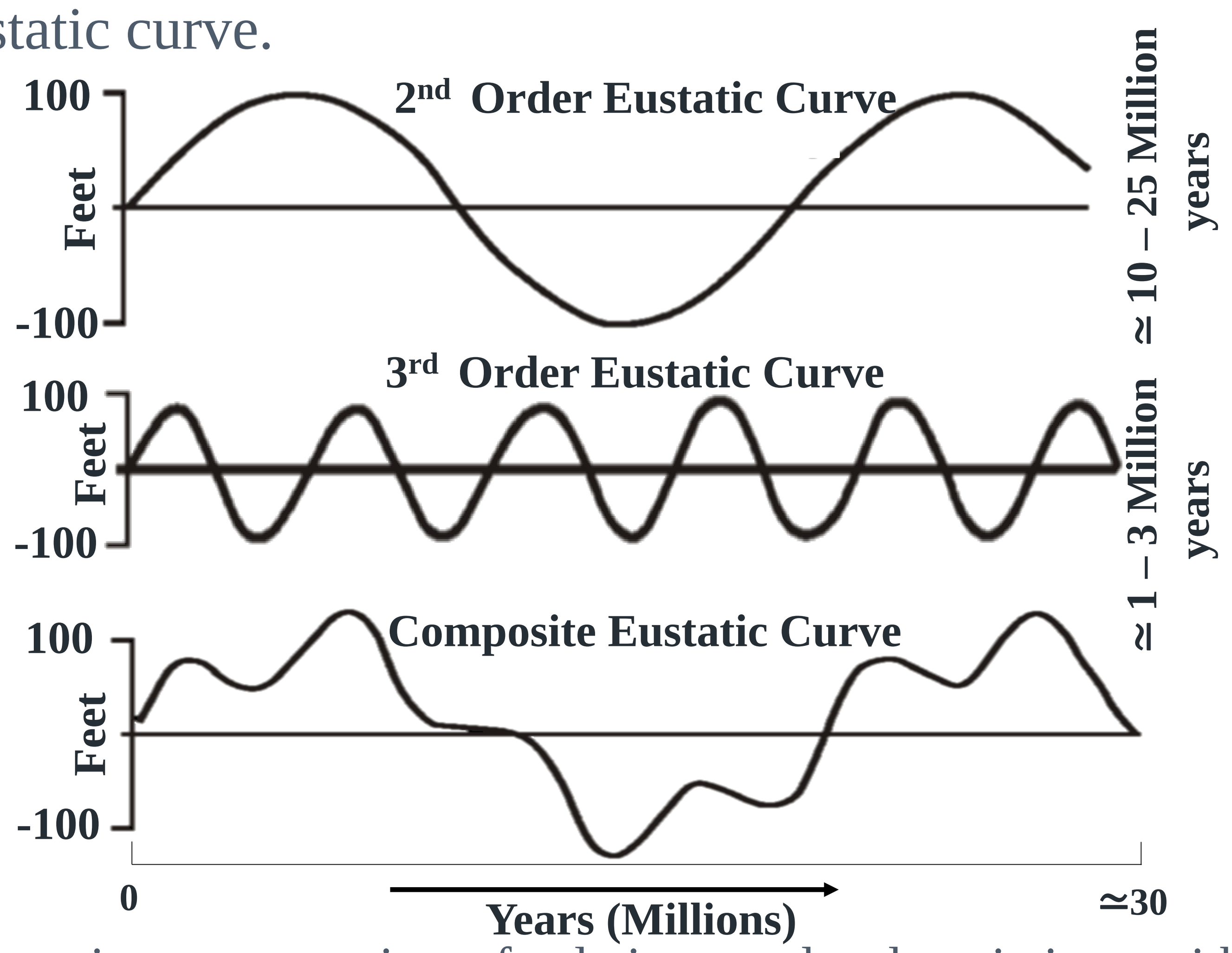


Figure 2: Schematic representation of relative sea level variations with time curve. Horizontal axis represents time in tens of thousands to millions of years, while each curve has its own associated vertical axis (in feet) representing the height variations of relative sea level. 2nd order and 3rd order Eustatic cycles superimposed to Composite Eustatic cycle (shown from top to bottom) (Modified from Slatt, 2006; Slatt & Abousleiman, 2011).

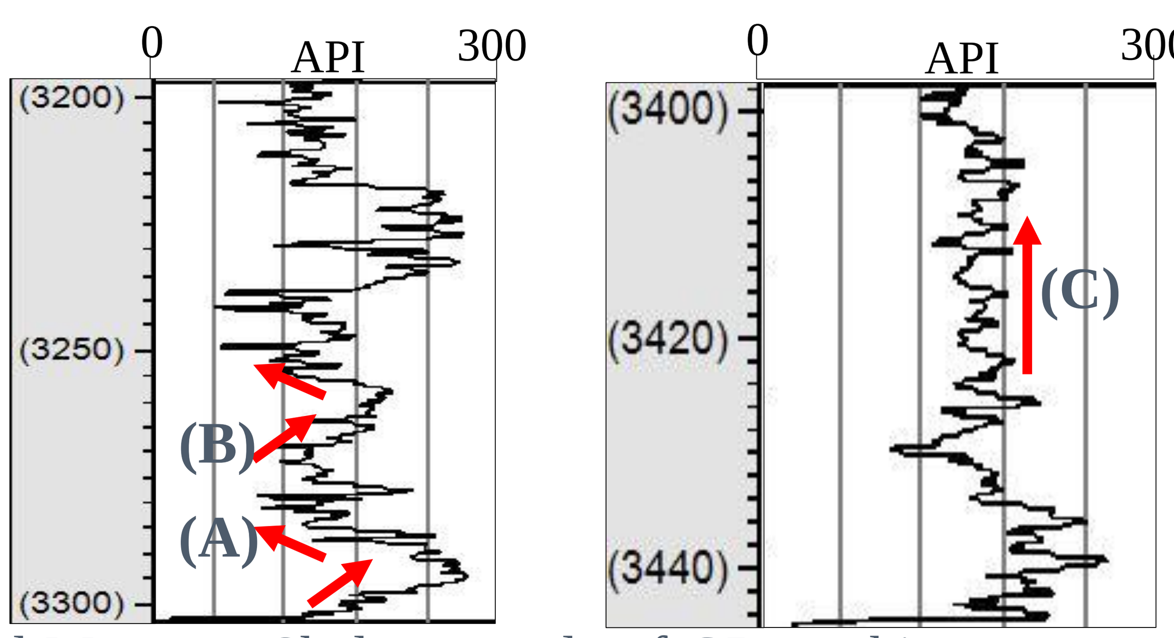


Figure 5: Roseneath and Murteree Shale example of GR stacking patterns (A) Upward decreasing (B) Upward-increasing (C) Constant. This is useful to delineate parasequences from log readings.

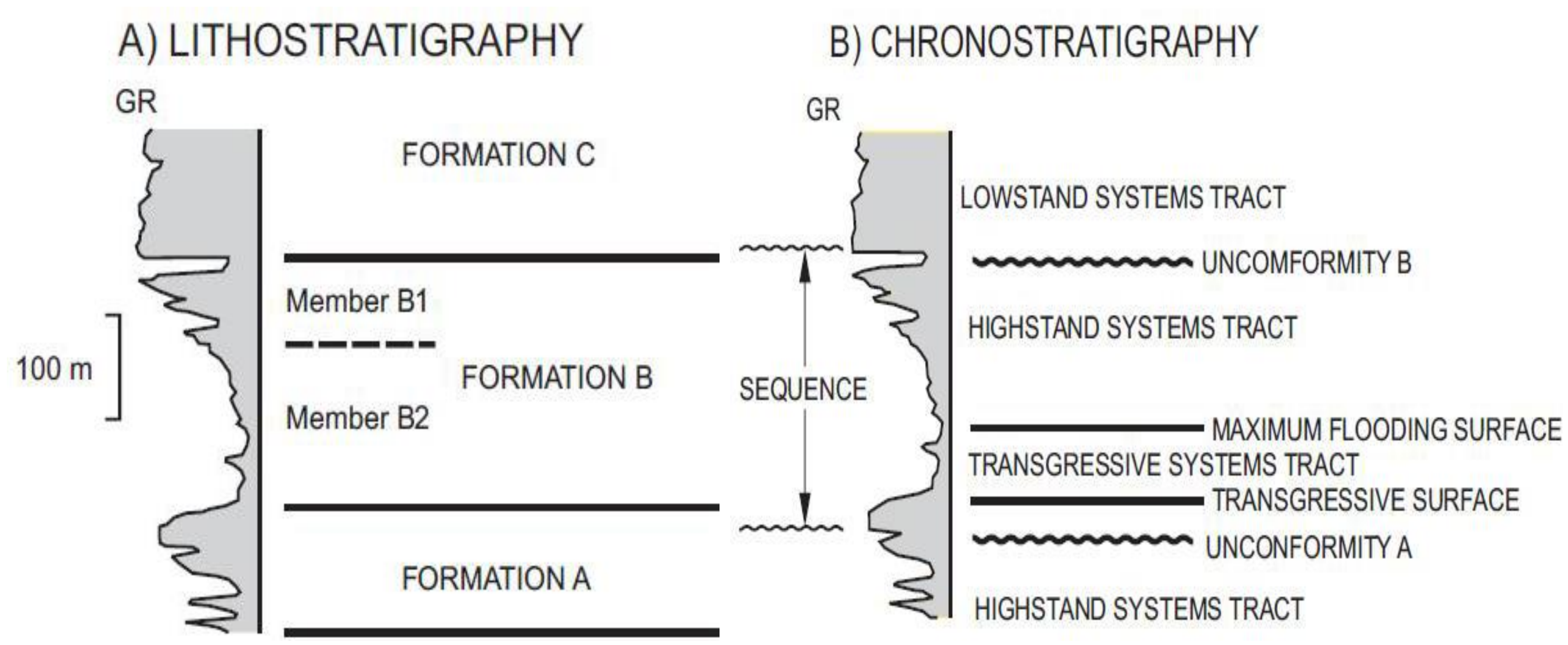


Figure 3: Common differences between lithostratigraphic (A) and chronostratigraphic (B) interpretations of gamma ray (GR) log. Tops for formations A, B, and C, and members B1 and B2 only bear lithological differences. Unconformities A and B delineate a full sea level sequence which convey information on major stratigraphic events and associated components. These sedimentary assemblages, Transgressive and Highstand Systems Tracts, Flooding surface, inferred from the Gamma Ray (GR) log provides an in-depth insight to the depositional environment, processes and energy of stratigraphic units and correlation of multiple well sections (Slatt, 2006).

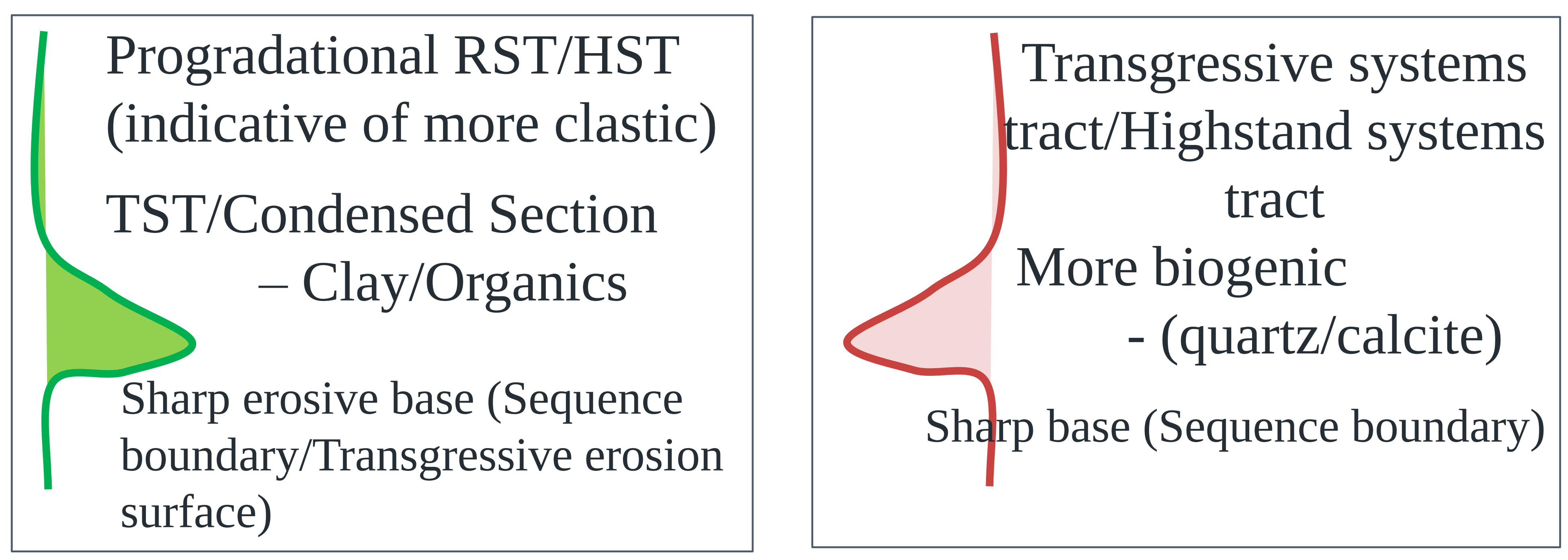
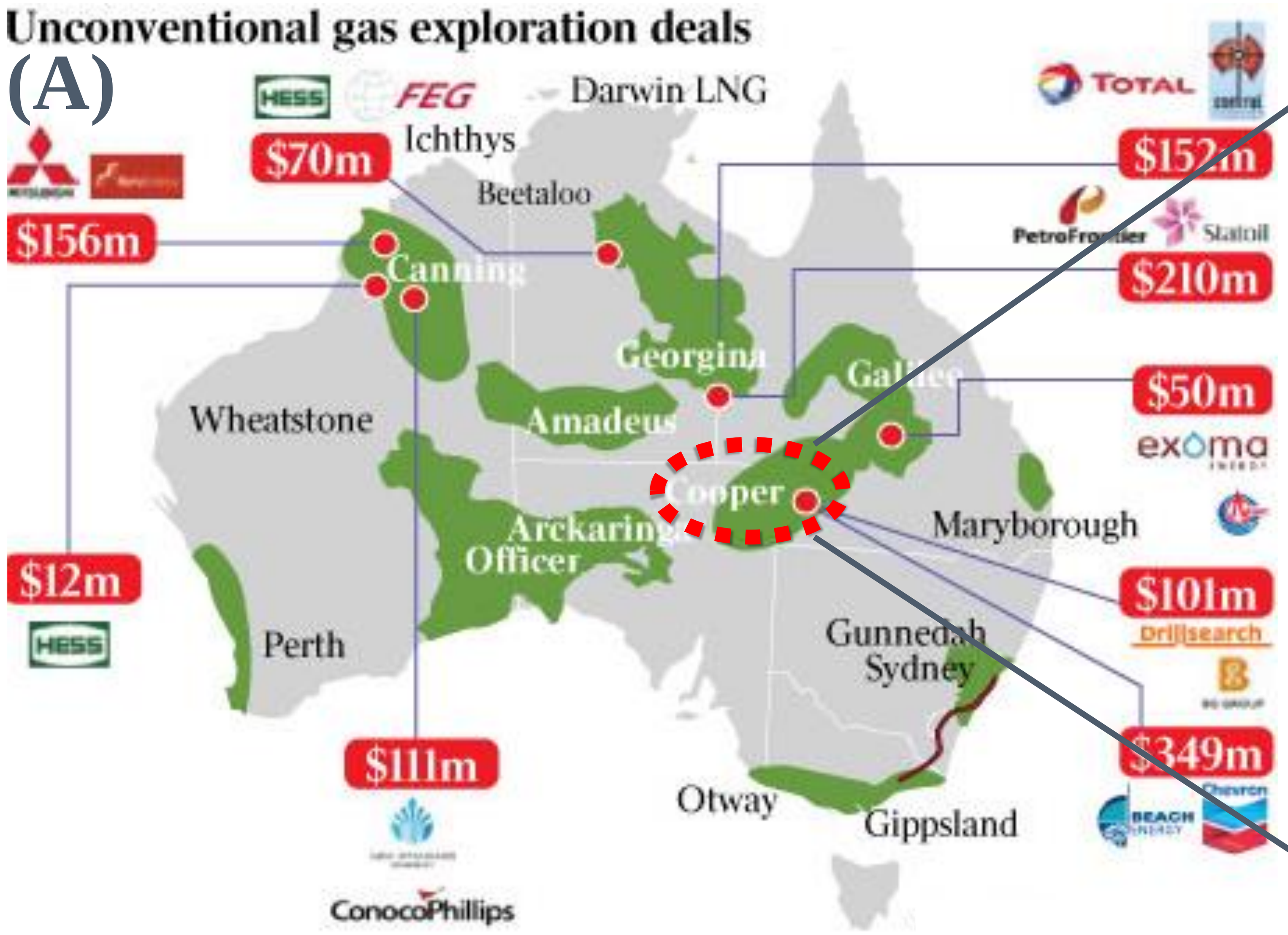


Figure 4: Representation of sequence stratigraphic model applied to Gamma ray signature for shale resource plays. Based on this approach, condense sections are the most prolific targets for resource plays developments (Slatt & Rodriguez, 2010).

ROSENEATH AND MURTEREE SHALE GEOLOGIC CHARACTERISTICS



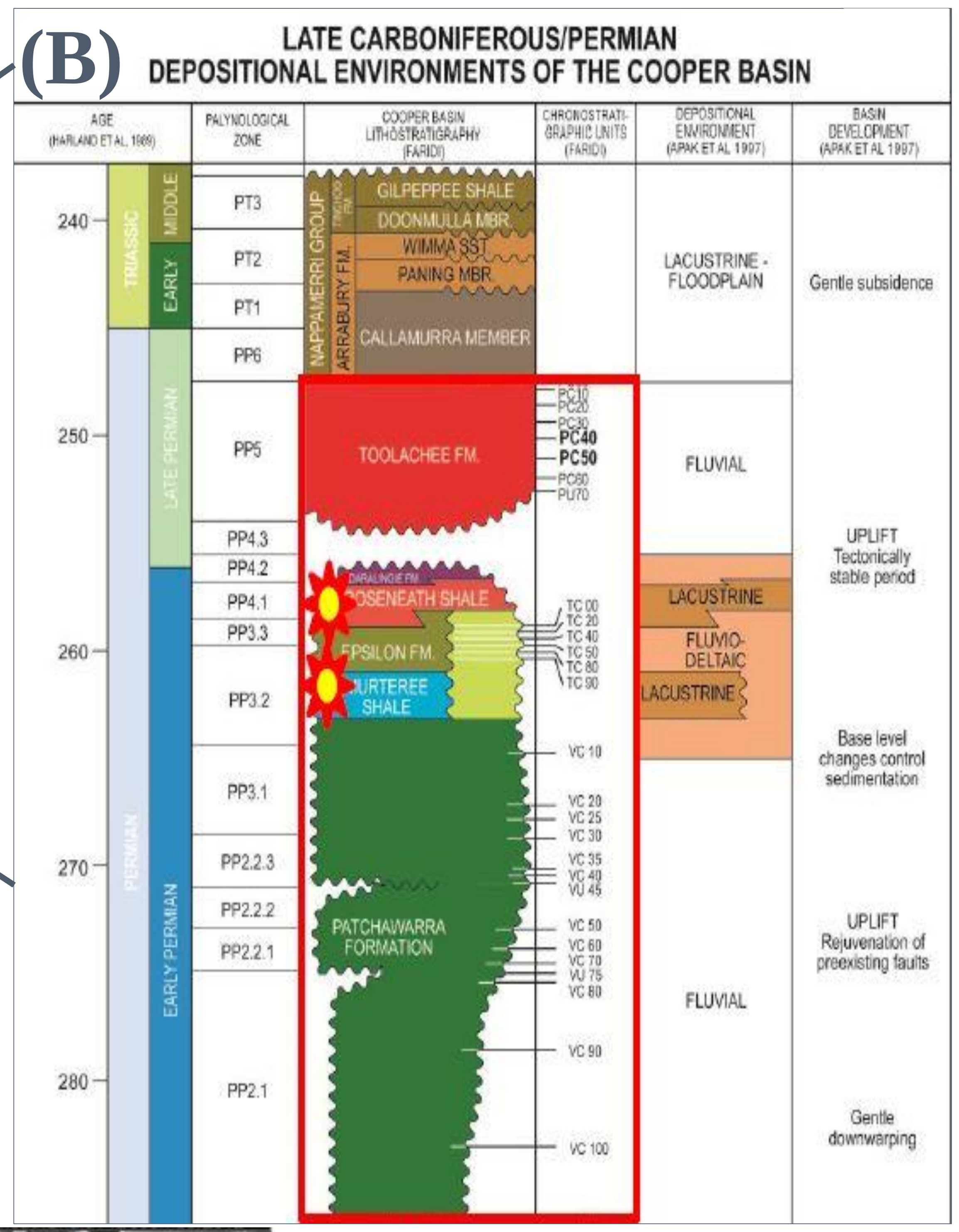


Figure 6: (A) Australian Sedimentary basins map and unconventional gas exploration deals (Relevant company announcements). (B) Stratigraphy of the Cooper Basin showing location of the Roseneath and Murteree (REM) formations interval (PIRSA, 2011).

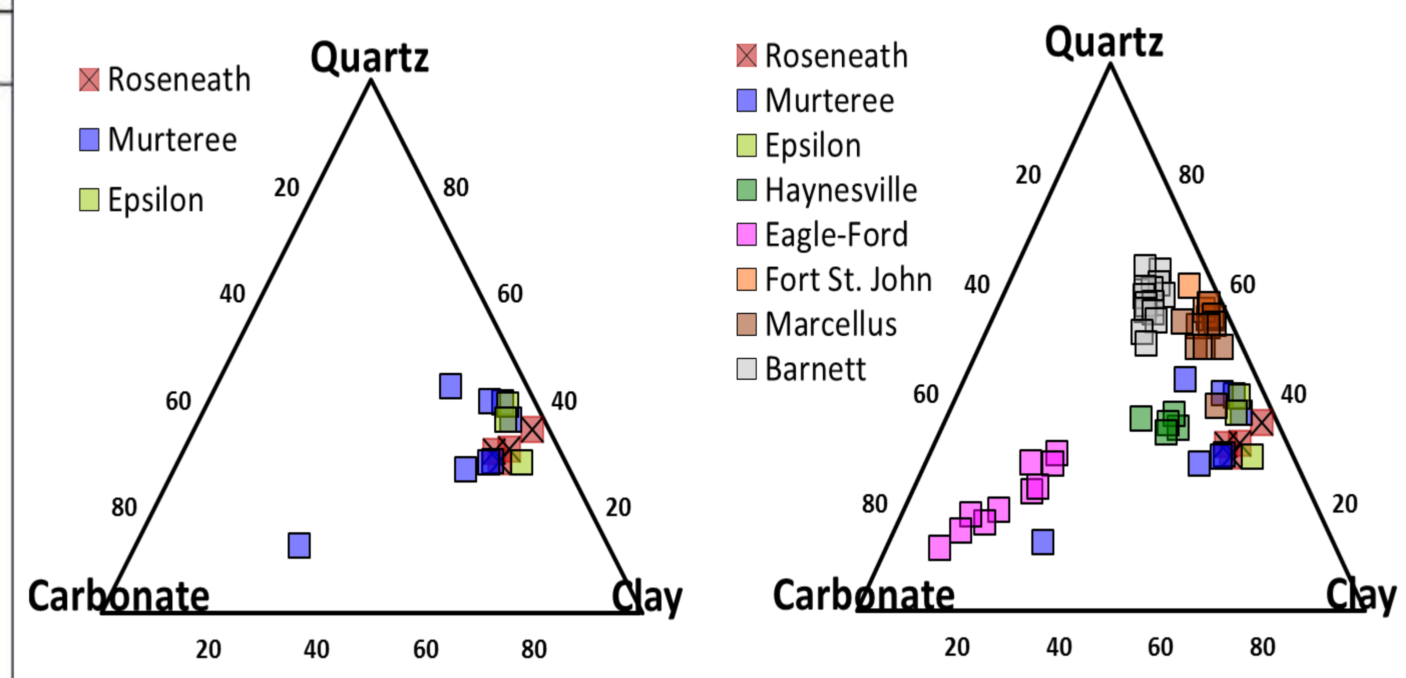


Figure 7: Ternary plot representation of the mineral composition of the REM shale (left), comparison with rich U.S shale plays (right) Compositional data for U.S. Shale plays obtained from (Jarvie, 2003; Bowker, 2003; Kohli & Zoback, 2013; Sone & Zoback, 2013).

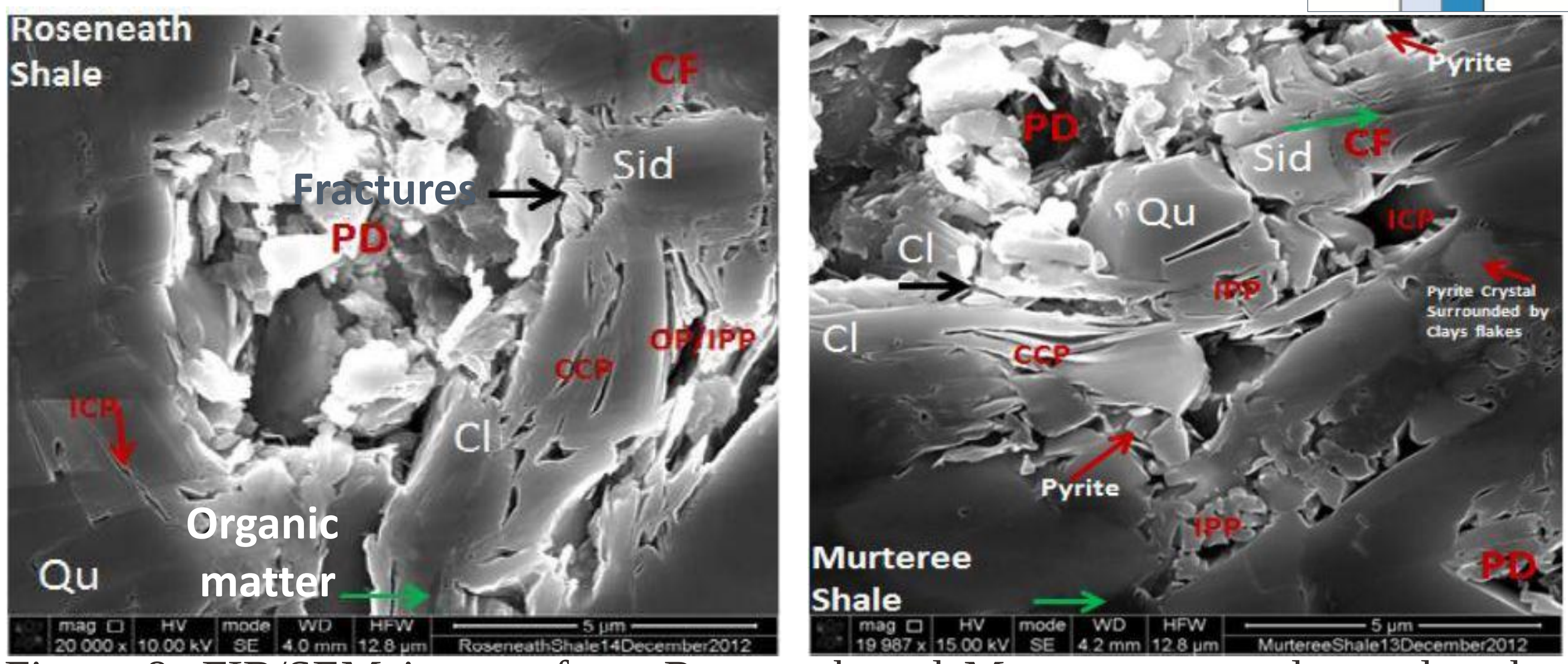


Figure 8: FIB/SEM images from Roseneath and Murteree scanned samples showing Intergranular porosity, Quartz, Siderite and Clay minerals (Ahmad & Haghighi, 2013).

Shales can be qualitatively described as either ductile or brittle, depending on their susceptibility to fracture. Often the degree of brittleness or ductility is defined based on the mineralogic composition by dividing the most brittle minerals by the sum of the rock constituents as shown below (Wang & Gale, 2009).

$$\text{Brittleness Index} = \frac{Q_z + Dol}{Dol + Q_z + C_a + Clay + + TOC}$$

However, mineralogic analysis does not measure stratification/lamination which is important to fracturability. Geomechanical properties (Young's modulus and Poisson's ratio) are also key contributors to fracturability (Figure 9).

MECHANICAL CHARACTERIZATION

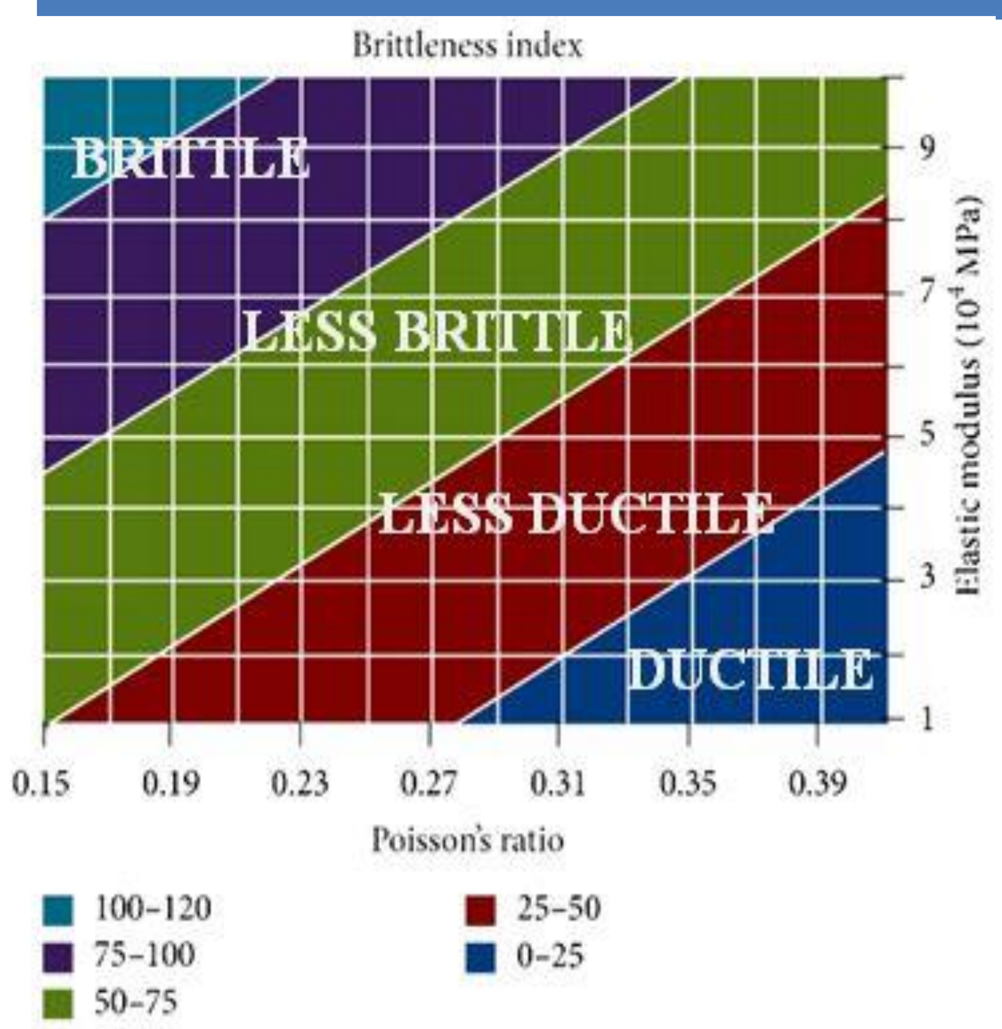
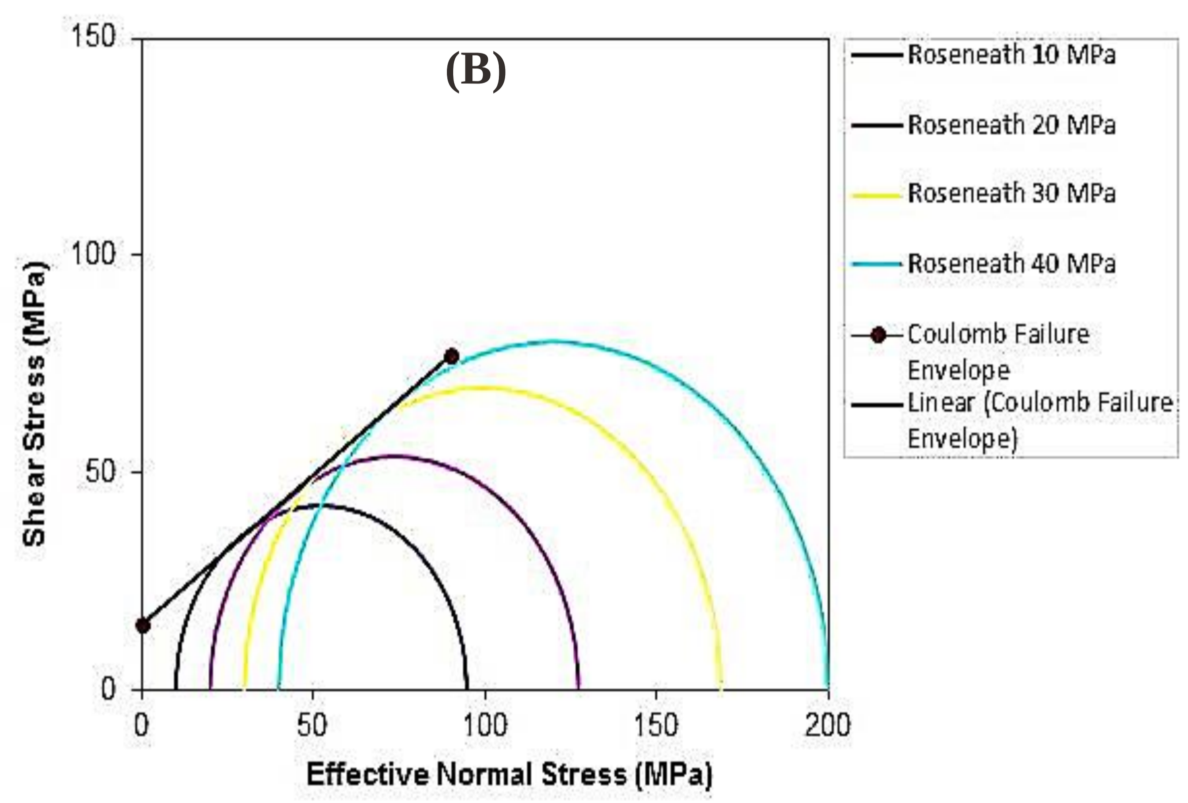


Figure 9: Shows a direct relationship between brittleness index and elastic properties – Young's modulus and Poisson's ratio. It can be observed that ductile rocks exhibit low Young's modulus and high Poisson's ratio, while brittle rocks exhibit moderate to high Young's modulus and low Poisson's ratio. Brittle rocks fracture easily when stress is applied while ductile rocks undergoes plastic deformation before failure.



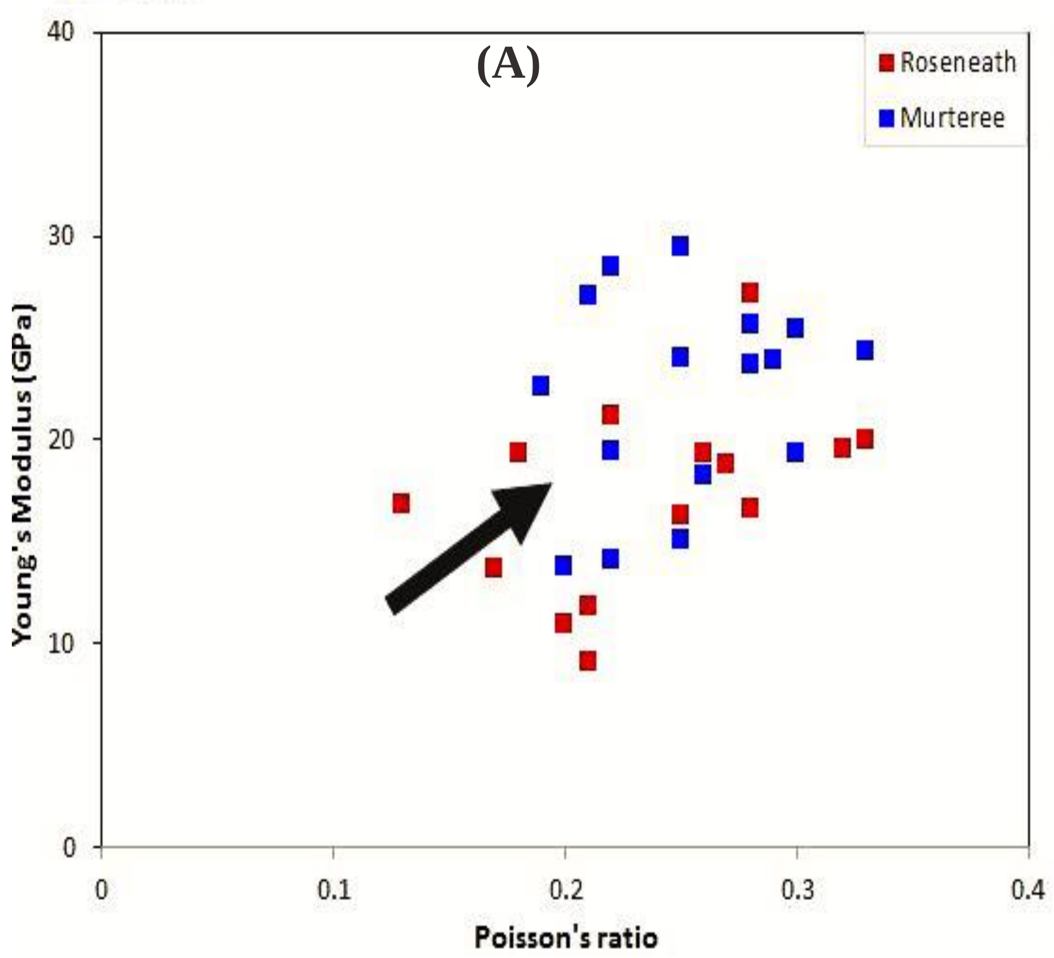


Figure 10: (A) Crossplot of Static Young's Modulus and Poisson's ratio for the Roseneath and Murteree shales. The arrow points in the direction of increasing brittleness (B) Mohr circles and failure envelope for Roseneath shale (Depth: 3516.8m). Friction coefficient of 1.31 and cohesive strength (16.24MPa). UCS of approximately 52MPa and friction angle- 32.6⁰

CONCLUSION

- Shale reservoirs exhibit logical, and predictable depositional sequence/ stratigraphy
- Sequence stratigraphy techniques provides a methodology for predicting and mapping ductile and brittle zones based on mineralogy and elastic properties at several scales of stratification (sequence, parasequence) in shale reservoirs (Fig. 11).

Sequence scale:
Lower ductile interval best for horizontal well because of high organics

Parasequence scale:
Allows for the identification and mapping more organic-rich intervals associated with adjacent brittle rocks

Bedsets/laminations:
Intervals with interbeds of organic rich and brittle rocks susceptible to fracturing.

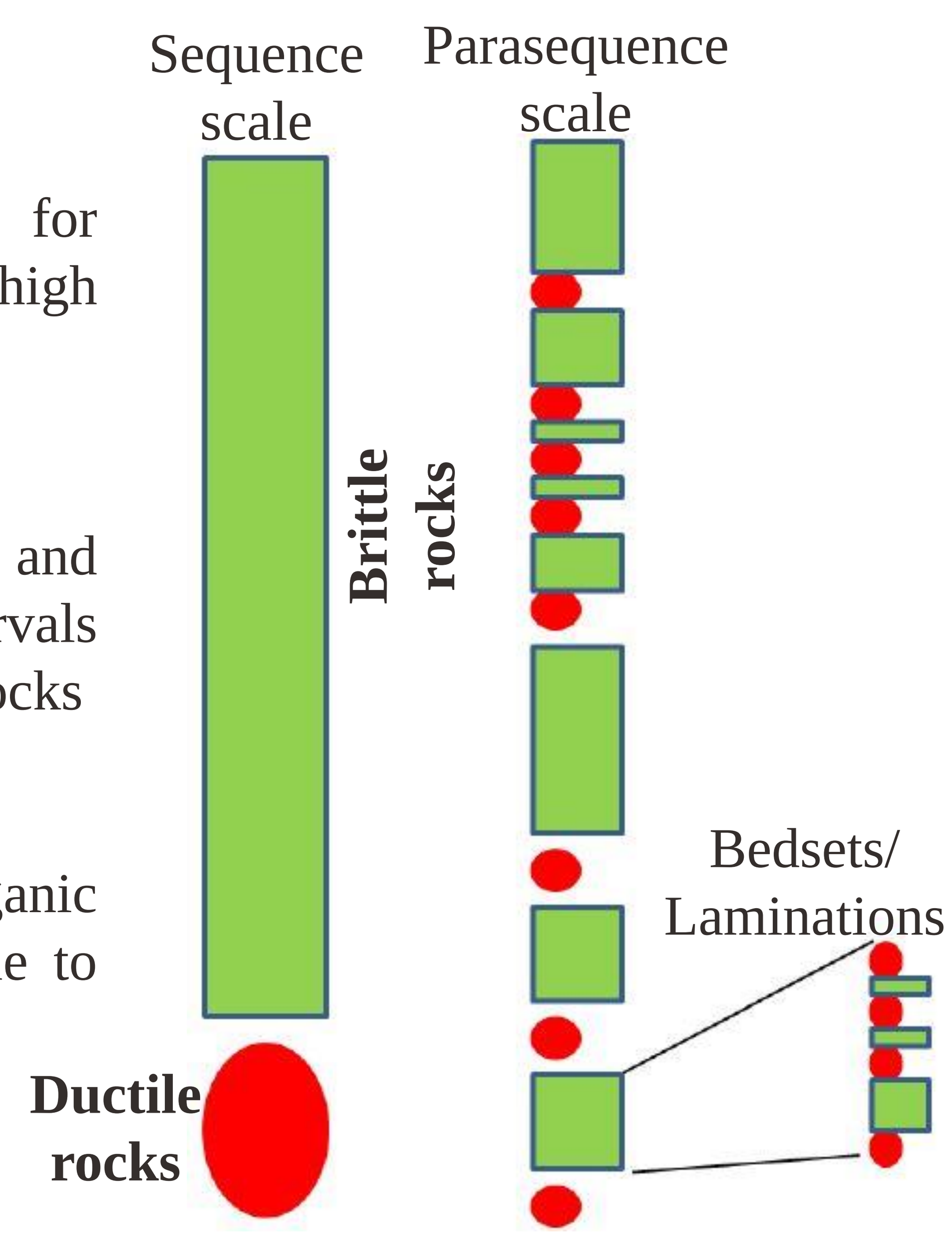


Figure 11: Predictable scales of stratification that can be identified in shale reservoirs (Slatt & Abousleiman, 2011).