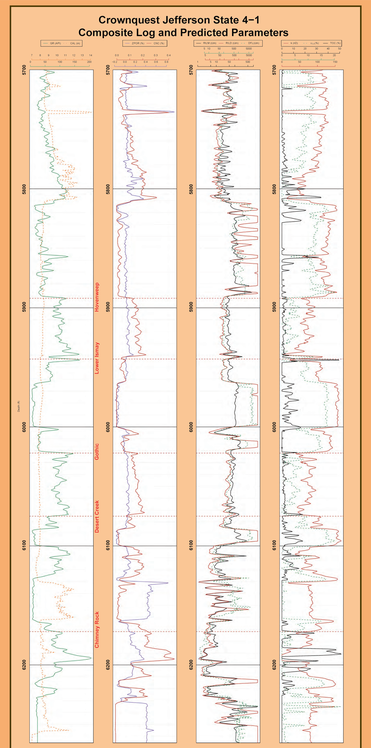
Petrophysics, Fractures, and Rock Mechanics

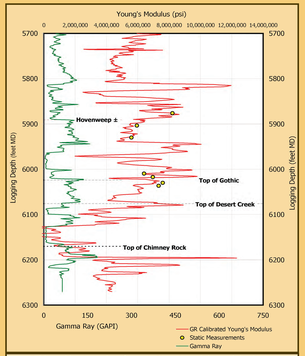


Composite log parameters found on three columns to left; right-hand column is presentation of three parameters (TOC, K, Phi-gv) predicated on core-to-log correlation, principally involving the major Pennsylvanian shale units.

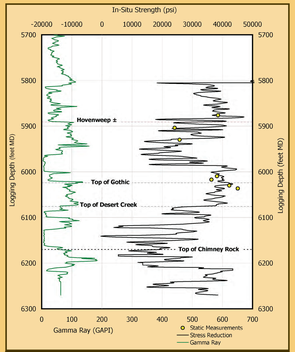
Closeup of selected (between 6031-6040.5 feet) Gothic shale sequence emphasizing healed and partially healed subvertical fractures. Reopening and reactivated fractures, and potentially opening along bedding features are relevant for stimulation. Effective production depends on interconnected fracture networks.

An oblique to bedding (~45°) fracture in the Gothic shale (at 5301.4 feet, in Aneth Unit H-117 well). Slickensides are evident. It has a veneer of calcite. The implications are that hydraulic fracturing may inflate/reactivate shear as well as tensile features.

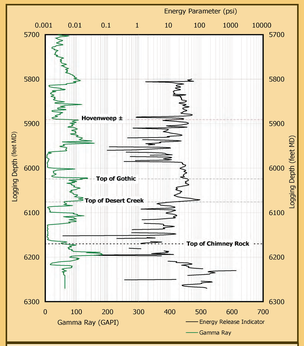
Jefferson State 4-1



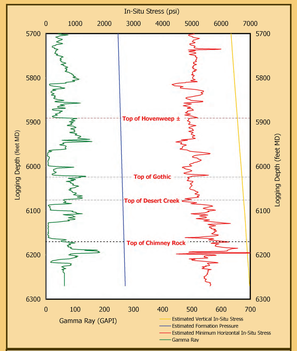
Calibrated logging values for static Young's modulus and the discrete laboratory measurements that were used for the calibration. After attempting numerous multiparameter correlations, it was determined that the best calibration relationship for Young's modulus used GR and DENSMA.



Logging inference of in-situ strength prediction (triaxial compression on as-received horizontal plugs with an effective confining pressure of 0.6 psi/ft was used to calibrate the data). Best calibration was based on the sonic porosity.



Logging inference of brittleness – based on estimates of stored energy. It is hypothesized and supported to some extent by the core graphs that the higher the stored energy, the greater the potential for fracturing during previous history. The energy stored and released was determined from laboratory triaxial compression testing; assessing the difference between the first evidence of inelastic behavior and the peak strength, and the characteristics of load reduction post-peak.



Vertical variation in the minimum horizontal stress (which controls vertical growth of hydraulic fractures), the vertical stress (which is commonly used in logging estimates of the minimum horizontal stress), and the inferred formation pressure. Stresses were estimated using logging relationships and experience – public domain corroborating evidence was not available.

Conclusions

Regarding Paradox Basin Shales

- TOC content ranges from 0.78 to 1.77 in the Jefferson State 4-1 well; kerogen types include I, II, and III.
- All three mudstone sequences are composed largely of dark brown-gray organic, calcareous mudstones with significant compositional dilution by terrigenous clastics
- Biotics include articulate brachiopod fragments, ostracods, microfossils of at least two types, inarticulate brachiopods, sponge spicules, conodonts, and conularioids—some biotics are transported, some indigeneous
- Compositional variation recognized through downhole logs mainly results from fluctuations in TOC content, in carbonaceous material, in dolomite/calcite, and in phosphate remains
- Matrix parameters recognized through refined porosity/permeability testing reveal that these mudstones are of minimally acceptable reservoir quality when compared to other known gas-productive shales
- Nonetheless, sustained production has occurred in this region from at least two of the three shales discussed in this paper.
- The in-situ stress conditions, although uncalibrated, indicate some degree of hydraulic fracture containment; but there is enough anticipated vertical growth potential to intersect immediately adjacent carbonate zones (with beneficial production), and in certain instances, salt (with undesirable production consequences)
- Production is likely enhanced when stimulation accesses (1) subvertical healed or partially healed fractures, which are pervasively present in the mudstones themselves, and/or in the stratigraphically bounding carbonates; and (2) when conventionally porous dolostones are either intimately interbedded or are found immediately above or below the mudstone sequence itself
- In the latter case of associated dolostones, a "hybrid" shale reservoir clearly results-- both conventional and unconventional sources of matrix voids will combine volumetrically for attained production recoveries
- Preliminary calculations of potential lithologic brittleness were carried out assessing the amount of stored energy and the rate at which this stored energy is released. More specifically, one looks for material that has a high strength and loses its load-bearing capacity rapidly on failure
- Once brittle zones are identified, inferences can be made for potential of reactivation of healed or latent surfaces during stimulation

Panel III

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Dislcaimer

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