Predicting Shale Characteristics with Integrated, Multi-Variate Statistics

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Oil and gas production in shale resource plays is dependent upon a number of factors including: rock strength, horizontal stresses, stress anisotropy, total organic carbon, thermal maturity, natural fractures, as well as a range of drilling and completions parameters. Traditional critical reservoir characteristics of thickness, matrix permeability, porosity and oil/gas saturation are also important - but far less dominant in shale resource plays. Effective *unconventional interpretation* in these plays demands integration across a breadth of: geochemical, geomechanical, geophysical, geological, petrophysical and engineering (production, completions, drilling and reservoir) data - to provide guidelines for where and how to drill and complete horizontal wells.

Simply stated, the goal of unconventional interpretation is to create reliable "sweetspot maps" as a guide to optimizing field development. These sweetspot maps can be grouped into four general categories - based upon whether they indicate: *where to drill*; *where not to drill*, *where rocks will break* and *how rocks will break*. Estimates of total organic carbon, thermal maturity, lithofacies and threshold thickness are some attributes that can be very defining of high productivity fairways (i.e. where to drill). Conversely, incoherence and curvature seismic attributes are valuable tools for identify faults, fracture chimneys and other hazards (i,e, where not to drill). Geomechanical and seismic estimates of elastic properties (shear, bulk and Young's moduli), Poisson's ratio (Vp/Vs), field measurements of breakdown pressure and core or other assessment of mineralogical clay-versus-silica/calcite/carbonate content are all useful indicators of spatial "crackability" (i.e. where rocks will break). Finally, estimates of maximum and minimum horizontal stresses, seismic velocity anisotropy and seismic curvature can all guide prediction of whether to expect simple (and ineffective) bi-wing hydraulic fracturing or more complex (and better draining) discrete fracture networks (i.e. how rocks will break).

Bivariate crossplot analyses of these various cross-discipline maps, with available production data like initial production (IP) or estimated ultimate recoverable (EUR) hydrocarbons, can often reveal interesting and useful trend information. However, variability in drilling and completions parameters generally limits effective calibration between well production and sweetspot maps. To remove, or at least reduce, these biases, we prefer to first apply a non-linear multi-variate analysis between available drilling and completions data. Typically, we will find strong correlations between well production and number of fracture stages, amount and rate fluid injection, surface pressure and, importantly, breakdown pressure. Breakdown pressure is the completion engineers' estimate of the pressure required to overcoming reservoir stresses and initiate and sustain hydraulic fracturing around the wellbore. Our investigations reveal a strong inverse linear relationship between breakdown pressure and production - the easier it is to fracture the rock, the more rock will be fractured.

The significance of breakdown pressure as a production predictor, as opposed to drilling and completions properties like fluid volume and rate, is that breakdown pressure is strongly dependent upon geomechanical rock strength, natural fracturing, in-situ stresses and other geologic parameters. In other words, the potential exists to predict how rocks along a wellbore will fracture, using one of more of previously discussed sweetspot maps. Again, using a non-linear multi-variate statistical approach, we concurrently analyze data from upwards of 60 different seismic volumes to identify the most unique and best predictors of breakdown pressure. The output from this workflows is a map of breakdown pressure, as illustrated in figure 1.
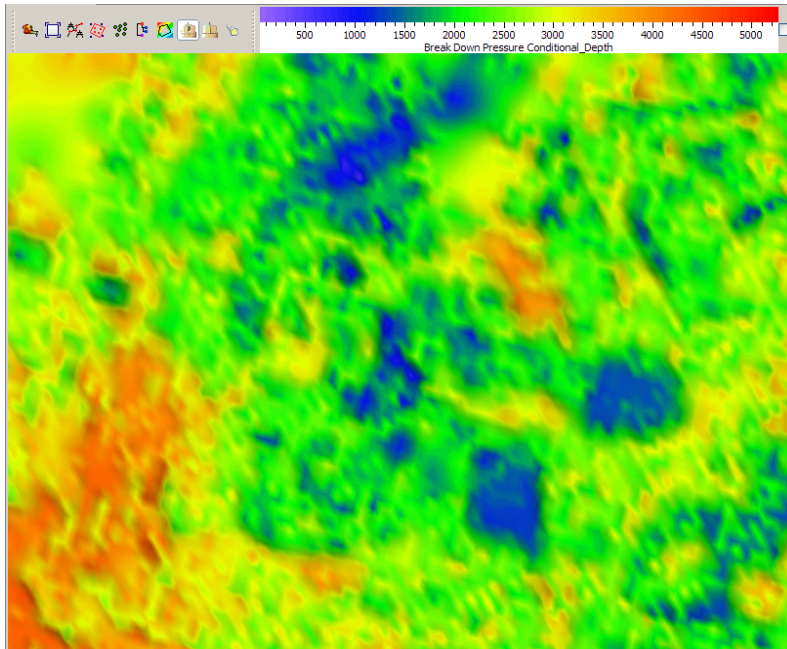
Figure 1: Multi-variate prediction of breakdown pressure. Blues are regions of more easily fractured rock and reds are regions where fracturing is more difficult.

Another output from this methodology is a mathematical relationship between multiple seismic attributes (or other maps) and breakdown pressure (and therefore, by extension, production). Coupled with an understanding of maximum stresses and natural fracturing, this map can be used for well planning - preferentially intersecting regions with consistently lower breakdown pressure. Furthermore, sensitivity analysis of input parameters is useful for identifying the important geophysical and geological attributes, to ensure physical plausibility of these relationships and provide options for reducing purchases of unnecessary and/or redundant seismic data attributes.

The techniques we have applied to map-based analyses have been extended to volumetric predictions of three-dimensional breakdown pressure. Also, breakdown pressures may be incorporated at a stage level along the wellbore, although care must be taken to ensure there is no stage-to-stage stress interaction that would distort the breakdown pressure estimates. Further workflow improvements are expected by incorporating maps of geomechanical rock strength and lithofacies.