AMPLIFIED GEOCHEMICAL IMAGING LLC

Technical Note

Mapping Reservoir Quality and Thermal Maturity Ahead of the Drill Bit in Shale Plays

The productivity of an organic shale is driven by reservoir quality (RQ) and completion quality (CQ). RQ consists of parameters such as effective porosity, organic content, system permeability, fluid saturation, net pay, hydrocarbons in place, and thermal maturity (Waters, 2019).

Traditionally this information is acquired from cores and cuttings. While seismic data can provide valuable insight into some of these parameters, interpretation of unconventional seismic data also requires calibration information from stratigraphy, sedimentology, and petrography to fine tune a calibration of seismic response to rock properties (Adcock, 2020). So, traditional answers for determining reservoir quality across a field require numerous wells to be drilled. Given the lack of RQ homogeneity in most shale fields, **the result is often inconsistent production, particularly in the early stages of the drilling campaign**.

Unlike other technologies, **Amplified Geochemical Imaging can identify RQ across a field ahead of the drill bit, or with just a few wells.** AGI's ultrasensitive surface hydrocarbon mapping is based on microseepage. Microseepage is driven by four primary factors: pore pressure, porosity, net pay thickness, and hydrocarbons in place (i.e. reservoir quality) and can map thermal maturity transitions as well.

The existence of microseepage is supported by a large body of empirical evidence (Price, 1986; Klusman, 1993; Klusman and Saeed, 1996; Matthews, 1996).

This RQ case study took place **in the Anadarko basin** in southwestern Custer County and southeastern Roger Mills County of western Oklahoma. The purpose of the survey was to map over pressured gas condensate from the Pennsylvanian Red Fork channel sands at a depth of ~14,000'.

The paleodepositional model, see **Figure 1**, shows the Red Fork sand system that consists of a deltaic complex to the north, with significant oil and gas production, with deep water turbidite fans and channels to the west, and over-pressured gas production from numerous fields across Roger Mills and Custer counties. The red star represents the survey location.

An AGI survey was performed to identify the most prospective areas in the field. **Figure 2** shows a plot of

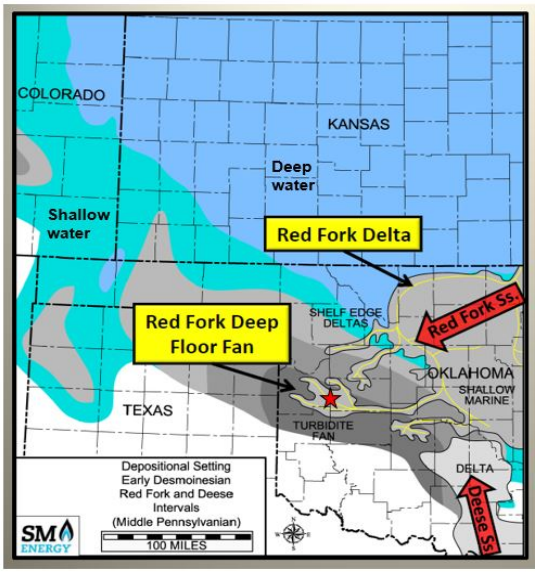

Figure 1.

the AGI probability factor on the Y axis versus porosity* net pay (phi-h). The plot **shows strong a correlation (i.e. $r^2 = 0.87$) between effective porosity (ϕ), net pay thickness (h), and the surface geochemical expression**. The AGI probability factor is also a function of reservoir pressure, but pressure is assumed to be constant across these over-pressured channel sands.

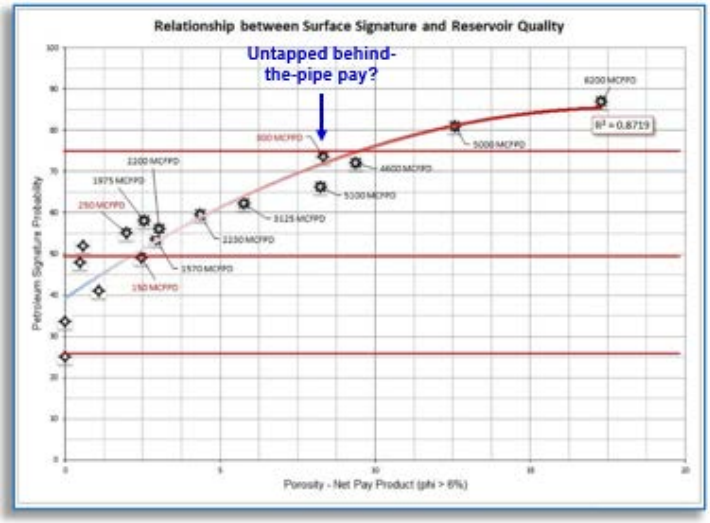

Figure 2.

The graph shows dry wells and sub-economic wells with a probability factor ranging from ~50% - 60%. This is important to note because phi-h in channel sands or turbidite complexes can be highly variable due to the

Identify Field Sweet Spots with Minimal Well Control

the extension and retraction of turbidite fans. Note as the AGI probability factor increases, production also increases. This is a reflection of more hydrocarbons in place. Thus, the graph demonstrates the ability of the AGI data to identify and map areas of higher porosity, net pay thickness and hydrocarbons in place (**i.e. Sweet Spots**).

The **data clearly demonstrate the correlation of AGI probability factors to reservoir quality and production.** These high reservoir quality and production locations were predicted prior to drilling.

The second case study took place in the **Marcellus shale play** in northeast Pennsylvania where the Marcellus is at ~8,000 ft. The northern portion of the survey was situated within a zone of shale maturity, and included gas production from multiple laterals. The southern portion of the survey included two dry wells. The purpose of the survey was to define the transition (i.e. the "Line of Death") in the shale gas maturity from north to south.

The client had well control in the north, very little well control in the south and no well control between the two. For the survey design, see **Figure 3**, 120 modules were used in a grid pattern over the area of interest. The survey was comprised of parallel lines of geochemical samples with ½ mile spacing from north-to-south and 1 mile spacing from east to west. The results are seen in **Figure 4**. The red areas represent an 85%-95% probability of finding dry gas (i.e. hydrocarbons in place), enhanced porosity and higher pore pressure.

The light green color indicates poor prospectivity, while blue is background or nonprospective areas. The results also identify the "Line of Death".

Note only 2 of the 9 producing wells in the north are in high prospectivity areas.

Thus, 78% of the producing wells are not in areas of maximum RQ.

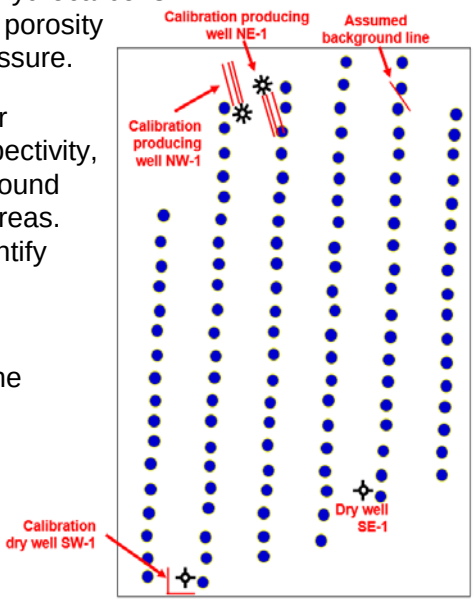

Figure 3.

The AGI anomaly map also shows that the company had not yet drilled the most prolific parts of the field.

Notice in **Figure 4 the significant difference between the positive dry gas signature and the negative dry well or background signature.**

AGI was originally told SW-2 was a dry well, yet the survey results indicated otherwise. AGI was later told SW-2 was not dry, but a gas well that had been P&A'd, **thus, ground truthing the AGI findings.**

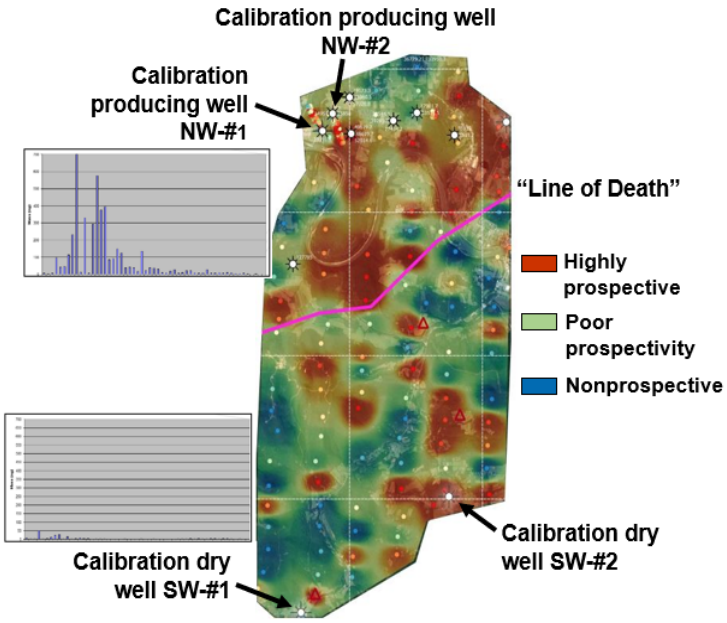

Figure 4.

Summary:

Traditional methods only allow reservoir quality assessment one well at a time. The use of AGI geochemical surveys allow for the assessment of heterogeneous RQ across the entire field, with minimal well control as shown in this Marcellus case study.

The Anadarko basin study verified the relationship of AGI probability factors to pore pressure, porosity, net pay, and hydrocarbons in place, **all of which directly relate to profitability**.

The Marcellus case study also showed how those RQ parameters can be mapped field-wide and identified the yet untapped undrilled prospectivity in the play as well as the highly nonprospective areas to the south.

This capability has been used in the Marcellus, Utica, Eagle Ford, STACK, and the Permian plays.

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