A Petrophysical Model to Quantify Pyrite Volumes and to Adjust Resistivity Response to Account for Pyrite Conductivity

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Abstract

In previous publications by the Authors (AAPG 2011, 2012) a petrophysical methodology was introduced to examine the constituents of unconventional gas and oil reservoirs. Using triple-combo open-hole logs, components in the clean formations are examined separately from shale components.

In many reservoirs associated with organic-rich shales, pyrite is present. Sulfur is generated during the thermal maturation process, and if iron is present the result is the formation of pyrite. Petrophysical properties of pyrite are unique – a very high grain density of 5.0 g/cc, and a very high electrical conductivity of 2703 mmhos/m.

The presence of even small volumes of pyrite can be inferred from anomalously high grain density. By comparing grain density with conductivity, it can be verified if the high grain density readings are a consequence of the presence of pyrite. If pyrite is the culprit, a cross plot of grain density vs. conductivity will show a linear correlation of increasing grain density with increasing conductivity.

Interpretation of the data involves the choice of minimum grain density and minimum conductivity for the cloud of data representing pyrite-free formation. By assigning values to both minima, levels containing pyrite can be examined. Volumes of pyrite can be quantified by comparing grain density and conductivity with minimum values. Correct choices of minimum values should yield closely comparable volumes as determined from grain density and from conductivity. Mismatches may be a consequence of how the pyrite is distributed; disseminated pyrite has a greater influence on conductivity than does nodular pyrite.

When pyrite volumes have been determined, conductivity of pyrite can be subtracted from total conductivity, to yield pyrite-free conductivity. This will yield a more accurate assessment of the fluid components – more hydrocarbons, less water – than using original conductivity measurements.

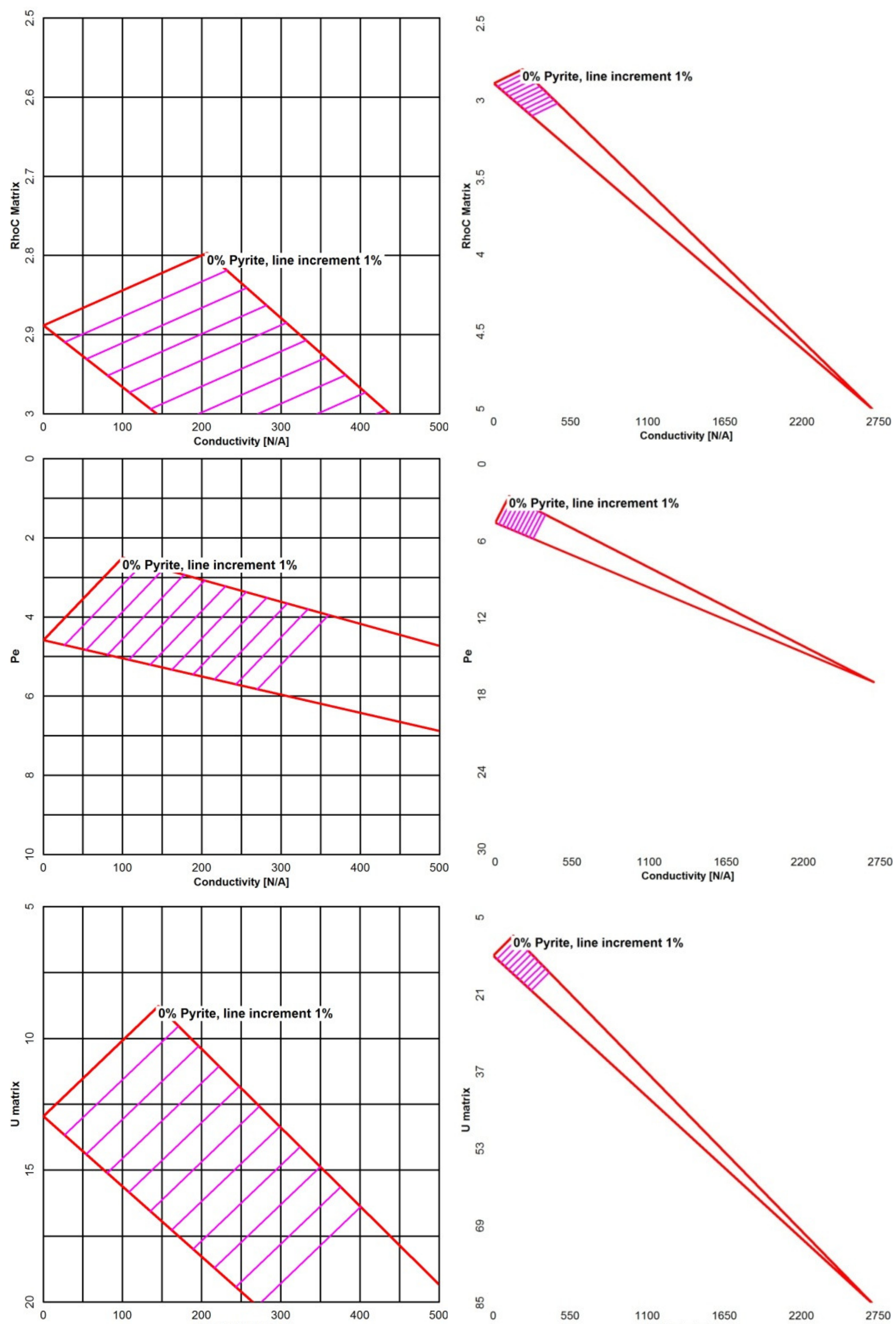
The methodology has important implications in the understanding of geochemical data. Quantification of pyrite volumes can be related to the thermal and migration history of the reservoir. There are also relations between sulfur content of crude oil and pyrite content, and this methodology allows calculation in wells with no geochemical data available.

Properties of Pyrite

Density	5 g/cc
Pe	17 b/e
Conductivity	2703 mmhos/m
Resistivity	0.27 ohmm
U matrix	85 b/e

Plots to Quantify Pyrite

Three plots have been proposed. All plots recognize the location of pyrite. The interpreter chooses data points considered to be pyrite free. A polygon is then corrected and scaled in volumes of pyrite.

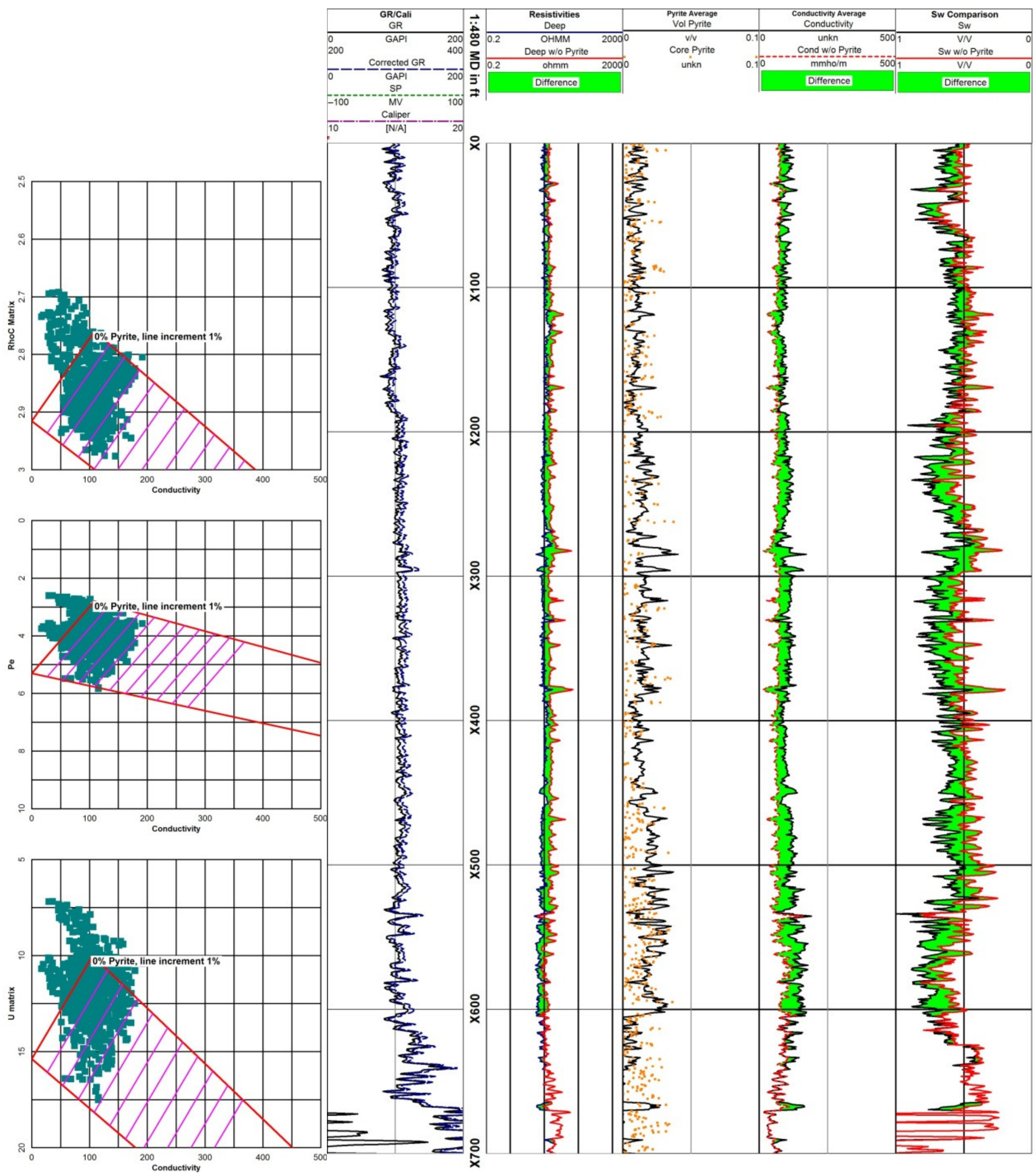


Methodology

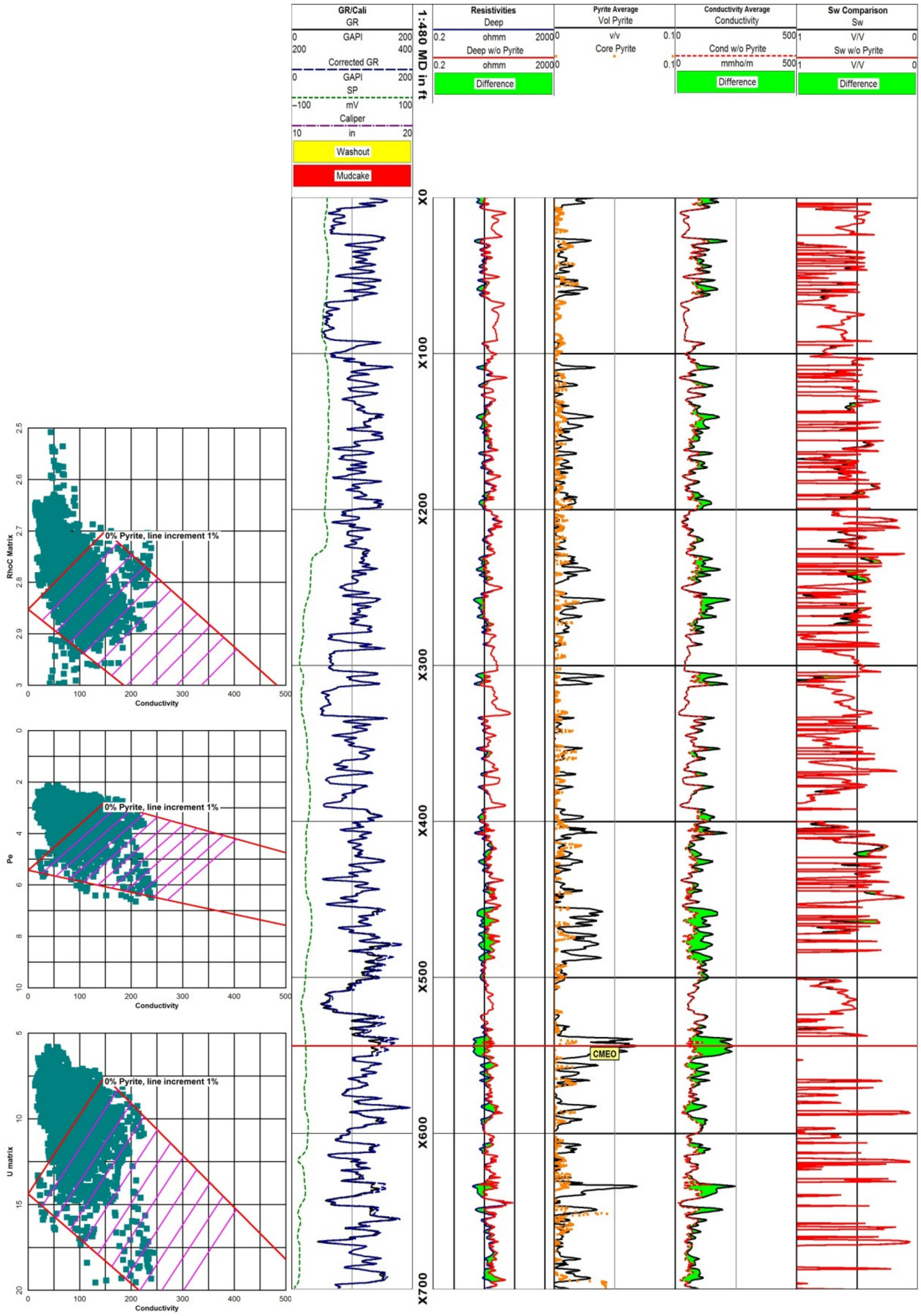
For each data point the volume of pyrite is calculated by the three different methods. Depth profiles of each calculation and an average of all three can be compared with XRD measured pyrite volumes. Additionally, knowing the conductivity of pyrite, the degree of conductivity increases due to pyrite can be determined. This conductivity increase can be subtracted from measured conductivity to yield a “conductivity without pyrite” curve.

The conductivity without pyrite curve is converted to resistivity without pyrite. By comparing with the original resistivity curve, the influence of pyrite on water saturation calculations can be examined.

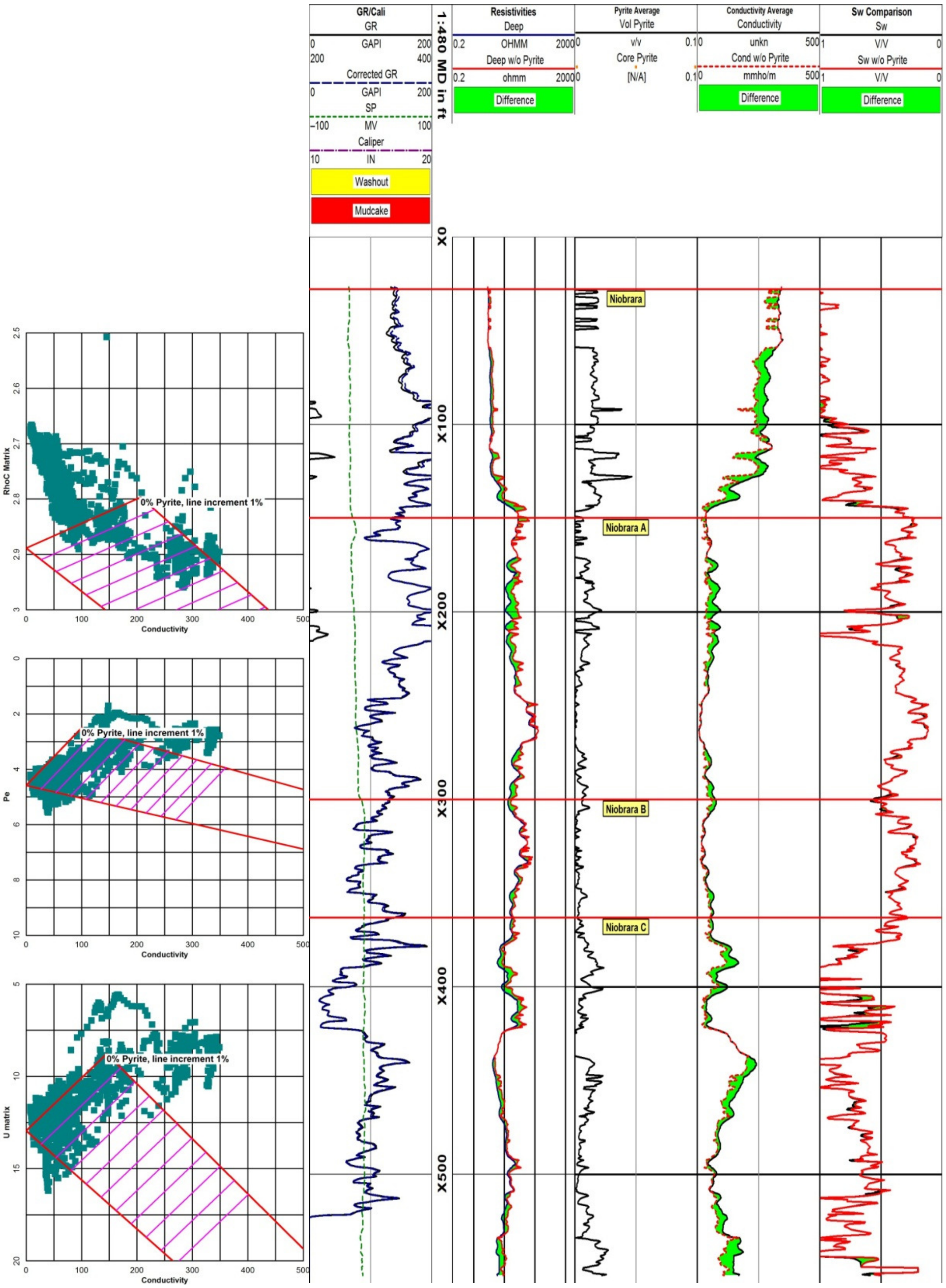
Example #1: Barnett, Texas



Example #2: Piceance Basin, Colorado



Example #3: Niobrara, Colorado



Conclusions

Pyrite is a commonly occurring mineral in many reservoirs. Even though volumes of pyrite can be quite low the influence on resistivity can be significant due to pyrite's extremely high conductivity of 2703 mmhos/m, equivalent to a resistivity of 0.27 ohmm. When water saturation calculations are made, spuriously high values will result unless corrections are applied.

Another influence of pyrite is related to the generation, migration, and accumulation of oil. Frequently oil migration is associated with high concentrations of sulfur. If there are iron-rich minerals (such as illite) in migration pathways sulfur will combine with iron to generate pyrite, whereas if there is no iron available, pyrite cannot form. The end result should be for reservoirs with pyrite, crude oil will be sweet, whereas reservoirs lacking pyrite will be sour. As demonstrated, pyrite volumes can be quantified; theoretically there should be correlations with crude oil characteristics.

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