**PS** Pitfalls in Geological Mapping Within Unconventional Plays: A Case Study From the Three Forks Play in the Williston Basin*

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Abstract

Historically geologists have identified oil and gas prospects by mapping a conventional reservoir's water saturation (Sw), porosity (Phi) and thickness (H). These three measurements proved to be reliable predictors of reservoir productivity and could be integrated into a single calculation, the SoPhiH map. In conventional plays, a SoPhiH map can be used to quickly identify sweet spots. In tight oil plays, however, SoPHiH maps can mislead operators as to where the highest yielding reservoirs are due to the complex nature of unconventional reservoirs and the necessity to hydraulically stimulate the rock. One example is the first bench of the upper Three Forks in the Williston Basin, where core helium porosities and water saturations, when averaged over the entire reservoir interval, are relatively consistent over large areas. Since averaged Sw and Phi do not change significantly, areas with the greatest reservoir thickness calculate the highest SoPhiH. Operators have targeted areas with the thickest first bench but unfortunately, the zones with the highest calculated SoPhiH ultimately proved to have some of the poorest production. This is due in part to the variability of different lithologies within the Three Forks and associated effective porosity and permeability. Careful identification and separation of lithologies and facies within the first bench and measurements of reservoir properties such as capillary pressure and brittleness within each facies are critical in identifying potential sweet spots. Unconventional production is impacted by many factors that are not included in SoPhiH maps and these maps should be used with care.

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**SoPhiH: The Good, the Bad, and the Ugly**

Riley Brinkerhoff, Sarah Edwards & Mark Millard

**Abstract**

Historically, geologists have identified oil and gas prospects by mapping a conventional reservoir's water saturation (Sw), porosity (Phi) and thickness (H). These three measurements proved to be reliable predictors of reservoir productivity and could be integrated into a single calculation: SoPhiH. In conventional plays, a SoPhiH map can be used to quickly identify "sweet-spots," where greater oil in place generally correlated with higher yields. In tight oil plays, however, SoPhiH maps can mislead operators as to where the highest yielding reservoirs are present due to the complex nature of unconventional reservoirs and the necessity to hydraulically stimulate the rock. One example is the first bench of the upper Three Forks Formation in the Williston Basin, where core helium porosities and water saturations, when averaged over the entire reservoir interval, are relatively consistent over large areas. Since averaged Sw and Phi do not change significantly, areas with the greatest reservoir thickness calculate the highest SoPhiH. Operators have targeted areas with the thickest first bench of the Three Forks formation, however, in the northern half of the Williston Basin, the zones with the highest calculated SoPhiH ultimately prove to have some of the poorest production. This is due in part to the variability of different lithologies within the Three Forks formation and associated effective porosity and permeability. Careful identification and separation of lithologies and facies within the first bench and measurements of reservoir properties, such as capillary pressure and brinnteness within each facies, are critical in identifying potential "sweet-spots." Unconventional production is impacted by many factors that are not included in simple SoPhiH maps, thereby limiting the effectiveness of SoPhiH maps. Simple and effective mapping methods include careful identification of effective reservoir rocks through capillary pressure measurements for effective porosity, UV photography, and careful gas show analysis. Since ineffective reservoir lithologies absorb frac energy and limit connectivity to better rock, ratios of effective and non-effective reservoirs often are helpful maps.

**SoPhiH Is a Great Mapping Tool**

Calculating SoPhiH from log or core data can be a quick way to map the potential productivity of a reservoir. The calculation contains three parameters that can easily be tied to the volume of hydrocarbons in place: So-the oil saturation of the reservoir, Phi-the porosity of the reservoir, and H-reservoir height.

![SoPhiH Is a Great Mapping Tool](image)

**SoPhiH Calculations versus Water Cuts**

Often in the Bakken/Three Forks play, lower water cuts correlate to better oil production. At the very least, lower water cuts lead to lower LOE costs. In some fields, SoPhiH mapping ties with lower water cuts.

![SoPhiH Calculations versus Water Cuts](image)

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In many fields in the Bakken/Three Forks play, SoPhiH correlates positively with production, even when engineering factors such as suction-type pumps and lateral placement are ignored. However, in the Three Forks play on the northern portion of the Williston Basin, SoPhiH often correlates inversely with production, with areas of low calculated SoPhiH greatly outperforming nearby areas of higher SoPhiH.

Key Questions

- Which intervals/lithologies contribute to production during the life of the well?
- Which tools/techniques are most effective in identifying and mapping effective reservoirs?
- How can we quantify the effectiveness of our current mapping strategy?
- As we better understand the factors that control productivity, how can we improve our lateral placement and stimulations?

Danger of Averaging Rock Properties

In many simplified cross-sections, average rock properties are used to determine the performance of a well. This approach may be misleading, as individual beds are thin, wireline logs often contain mixed lithologies only having a small portion that is effective. The brown dolostone, although it has high measured perm., appears to have water saturations and porosities that are much lower than expected. The mixed green and brown mudstone shows what might be helpful to label the effectiveness of each facies. However, the laminated lithology in this sample has little effective porosity available and because what effective porosity it has is intercrystalline and intergranular porosity. Sample contains little matrix clay on average, but many areas have abundant horizontal to subhorizontal, open to clay-filled fractures. Thin section observations: Porosity within this sample is variable, but many areas have abundant water saturations and high measured perm. The brown dolostone has relatively low porosity but is almost all effective. This results in consistently low productivity. How can we improve our lateral placement and stimulations?

Summary and importance:

- MICP: Capillary pressure data shows at least two pore systems, a small but very permeable system and a larger but less permeable system.
- Thin section observations: Common, irregularly distributed, intercrystalline/intergranular pores, disturbed microstructure.
- Describe lithology and character for lithofacies: Mixed green and brown breccia.

What is Effective Porosity? How Can We Better Understand the Pore Systems?

In the Three Forks play, clay is a controlling factor on the effectiveness of each facies. Although it increases pore-throat connectivity and pore-throats, it also increases fluid capillary pressure. The brown ton, silty to sandy dolostone shows which intervals are most important. The laminated lithology in this sample has little effective porosity available and because what effective porosity it has is intercrystalline and intergranular porosity. Sample contains little matrix clay on average, but many areas have abundant horizontal to subhorizontal, open to clay-filled fractures. Thin section observations: Porosity within this sample is variable, but many areas have abundant water saturations and high measured perm. The brown dolostone has relatively low porosity but is almost all effective. This results in consistently low productivity. How can we improve our lateral placement and stimulations?

Summary and importance:

- MICP: Capillary pressure data shows a single pore system that has high entry pressure.
- Thin section observations: Overall, this sample contains low porosity; porosity is most abundant horizontal to subhorizontal, open to clay-filled fractures.
- Describe lithology and character for lithofacies: Mixed green and brown laminated.

Summary of perforations for the Three Forks First Bench

- Mixed green and brown breccia
- Average composition: 44% dolomite, 23% quartz-feldspar, 25% clay minerals
- 1st System: 0.0006 mD MICP Perm
- 2nd System: 0.0003 mD MICP Perm
- 3rd System: 0.043 mD MICP Perm

Summary of perforations for the Lower Bakken Shale

- Mixed green and brown breccia
- Average composition: 39% quartz-feldspar, 21% dolomite, 22% clay minerals
- 1st System: 0.0303 mD MICP Perm
- 90.3% Sw
- 6.4% Phi
- Pd 328 (psia)
- 1st System: 0.00016 mD MICP Perm
- 2nd System: 0.0006 mD MICP Perm
- 6.5% Phi
- Pd 3.4 (psia)
- 5.5% Phi
- Pd 451 (psia)

Danger of Averaging Rock Properties

- Which intervals/lithologies contribute to production during the life of the well?
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Mapping Workflows for Unconventional Rocks

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Better Mapping Methods

- Identify the zones/lithologies that are most likely to contribute to production.
  - What are the properties of potential flow units/reservoirs?
  - Standard core analysis
  - Lithology reports

- Which zones are likely to act as barrier/ baffles?
  - Rocks that isolate potential flow units
  - High stress fracture barriers

Collect and use capillary pressure data

- Use capillary pressure curves to quantify the effective porosity in each facies
  - Does the MICP porosity and air porosity correlate?
  - Is there enough storage in the effective porosity to make a prospect?

- Is there enough oil column height or overpressure to charge the identified facies?
  - If there is enough overpressure, do some of the non-reservoir facies become reservoirs?

Reality Check: Do the identified reservoirs fluoresce in UV photography? Do they have consistently strong gas shows?

- Brightest fluorescing intervals typically indicate mobile hydrocarbons
  - Facies with dim fluorescence have some oil saturation, but are unlikely to be high quality reservoirs

- Do your best facies give the strongest gas shows?
  - Does the gas fall off when drilling through the poorer facies?

Upscale reservoir and baffle facies from core to log scale

- Group similar core lithofacies
  - Rocks with similar effective porosity measurements and saturations should be grouped into a single log lithofacies

- Often intervals with low effective porosity can be grouped using clay cutoffs
  - Caution! An interpreter could end up in the original SoPhiH problem if facies are grouped too broadly

- Using a normalized log dataset, identify log characteristics that are unique to the log lithofacies
  - Are the log lithofacies broad enough to be mappable?
  - Scale log resolution by the foot, not inch

Do the log lithofacies make sense on a regional scale?

- As the facies are picked across miles and then tens of miles, does the grouping scheme still make sense?
  - As formations change laterally, are new lithofacies designations needed?
  - Don’t force rocks with different properties into a simplistic average

Do the resulting maps tie to production trends?

- Do the mapped log lithofacies correlate to production?

- Do ratios of good to poor lithofacies correlate better?

Upscale 3rd Bench Ratio vs Production

Be Aware of the Entire Petroleum System

- Local conditions such as tectonic fracturing, thin or brittle shale intervals, or highly permeable zones in the overlying Lower Bakken Shale and Middle Bakken could have significant impacts on Three Forks productivity.

- Do structural features or stratigraphic trends in adjacent sediments tie better to production trends than Three Forks stratigraphy?

- An important limitation in SoPhiH calculations in unconventional reservoirs is that we don’t often know how much H is effective.

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