Dynamic Integrated Data Analysis of a mature hydrocarbon basin – A case study from Wyoming's Bighorn Basin

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1. Abstract

When assessing mature hydrocarbon basins, objective evaluation of big data sets and large geographic areas can pose challenges. Namely, knowledge bias for an area can occlude a higher potential for production in another area.

This study presents results from an assessment of existing and undiscovered oil resources in the Bighorn Basin (BHB), using an original method to dynamically evaluate large data sets. The assessment is based on a range of geologic elements and historic production data for individual stratigraphic intervals and for the basin as a whole—all available from public resources.

The BHB contains 134 oil fields, seven of which fall within the state of Wyoming's top ten producing fields. Since its initial discovery in 1905, the BHB has produced more than 2.67 billion barrels of oil, and in 2011 Bighorn Basin production accounted for 22 percent of Wyoming's oil production that year. The maturity of this basin, the complexity of the petroleum systems, and the vast amount of publicly available data make this basin an ideal case study for dynamic integrated data analysis (DIDA).

This dynamic evaluation tool allows for on-the-fly parameter adjustment and a virtual comparison of probability for success. Parameter significance can be based on many factors, including data density and quality—which are key considerations in mature basins where data comes from a range of sources and vintages. For example, in the BHB, basin-wide porosity data is limited. Although porosity has the potential to significantly influence reservoir quality, the sparsity of the data set demands a more careful handling of this parameter in a basin-wide evaluation process. Being able to dynamically adjust the importance of different geologic parameters in a spatial framework allows one to evaluate and visualize the effect these parameters have, and improves probability mapping.

Results from BHB data evaluation show that the dynamic integration of large data sets is a successful screening tool for seeking areas of high potential, with the ability to visualize and select relative parameter importance. The findings and methods presented in this study provide a fast and objective evaluation of mature and data-rich hydrocarbon basins across North America and around the world, and can be implemented by individuals or companies during an early phase of basin evaluation.

2. Why a Dynamic Evaluation Tool?

Evaluating large, publicly available data sets is often hampered by
- reporting inconsistencies
- data quality issues,
- analysis bias.
- spatial analytical tools of large data sets do not allow for the analysts to easily and quickly test a multitude of what-if scenarios.

Early versions of this project:
- Highlighted counties of interest in the western US
- Evolved to investigate field-scale probability of success within a basin
- Sought sub-field-scale screening, which required weighting, summing, and reconfiguring up to 55 GIS layers at once
- Needed a workflow to easily management such a large number of data layers

Figure 1A:

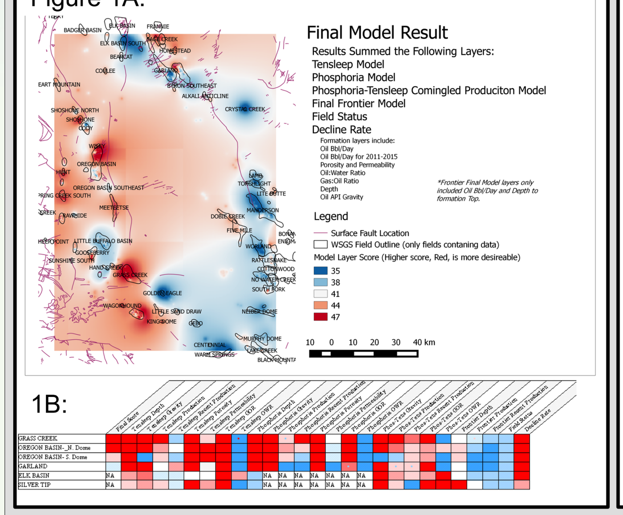
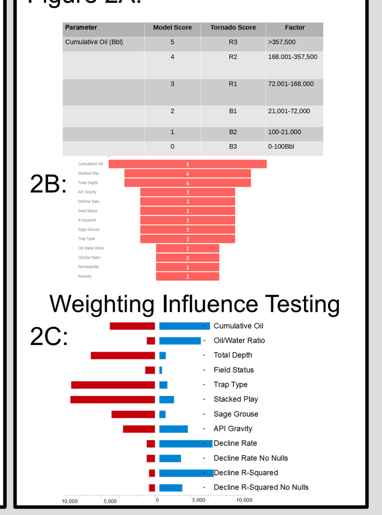


Figure 2A:



Project Goals

- Create a dynamic screening tool to evaluate large data sets
- Assess existing oil resources in the BHB
- Highlight marginal plays (for favorable tax treatment and low entry cost) with high probability of success

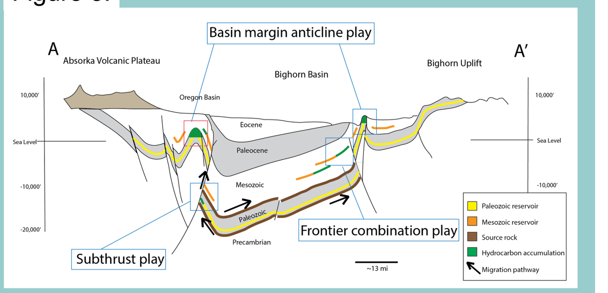
Above left box: Example of early field-scale probability mapping (Fig 1A), in BHB and field results heat map (1B). Red is more desirable; blue is less desirable.
Above center: Example of early weighting schemes (2A&B) and parameter influence on overall results (2C)

The Dynamic Integrated Data Analysis (DIDA) tool was designed to:
- **Save time in model iterations**
- Allow end user to determine desirable parameter ranges and weighting
- Allow project to run on desktop computers requiring less robust computational capabilities than was needed for early versions of this project for most of the work
- Replace trial-and-error scoring and weighting schemes with streamlined workflow

3. Why Bighorn Basin for Case Study?

The BHB is an ideal case study locality for dynamic integrated data analysis (DIDA):
- Complex petroleum systems with 134 oil fields (7 fall within WY's top 10 producing fields)
- Discovered in 1905, the Bighorn Basin produced >2.67 billion Bbl oil
- In 2011 BHB production accounted for 22% of WY's oil production that year
- **WOGCC provides a vast amount of publicly available data**

Figure 3:



Above (Figure 3): BHB cross-section and field play schematic. Major faults in black. See legend for explanation (Modified from Fox and Dolton, 1989).

Figure 4:

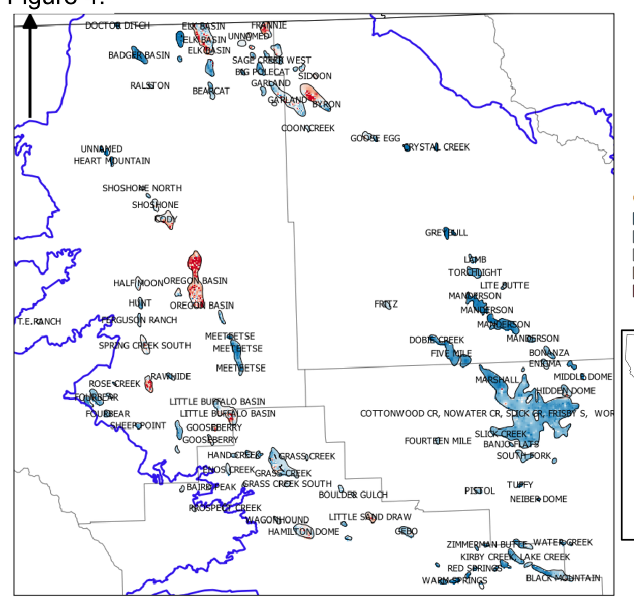
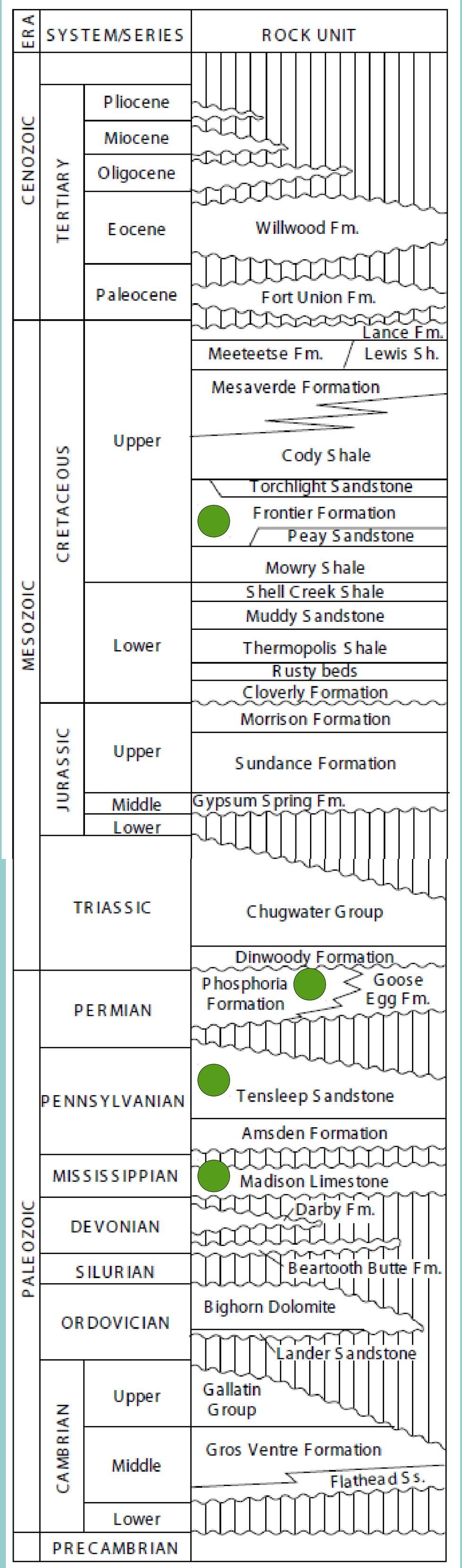


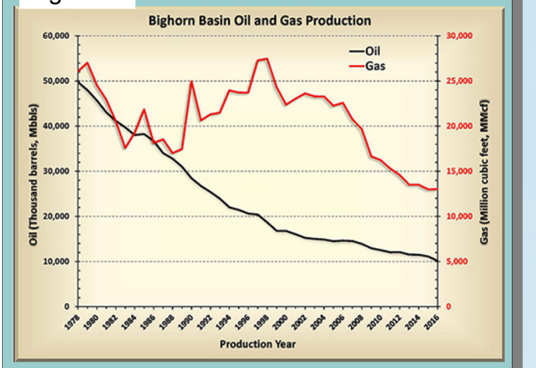
Figure 5:



Above (Fig. 4): Location of basin and BHB oil fields. Colored by cumulative production. This study investigated WY portion.
Left (Fig. 5): BHB Stratigraphic column. Green circles indicate oil reservoirs targeted in this project
- Frontier
- Phosphoria
- Tensleep
- Wells reporting co-mingled production from Phosphoria-Tensleep
- Madison

Right (Fig. 6): BHB production history offers many years of data

Figure 6:



(WSGS, 2017)

5. Dynamic Evaluation

Dynamic evaluation is a customizable query where parameter ranges are selected by the user, the DIDA tool replaces the raster value and assigns the weight value to portions of the map in the selected range.
The new maps are added together and divided by the sum of the weights and multiplied by 100 to scale for the color bar.

Right (Fig. 10): DIDA control panel allows users to determine desired parameter ranges. This project is based on:
- 2015 & 2016 Production (Gas:Oil ratio, Oil:Water ratio, Oil/day) by well
- Reservoir top depth
- Crude Oil API Gravity by well
- Porosity & Permeability (historic field-scale data with one reading per reservoir)

Below (Fig. 11) DIDA map with example of well point data density distribution within fields. Well points are colored by operator, to explore, for example, influence from different completion methods. Click on map to show location's data values; data interpolations between fields should be viewed critically where now data points exist.

Figure 11:

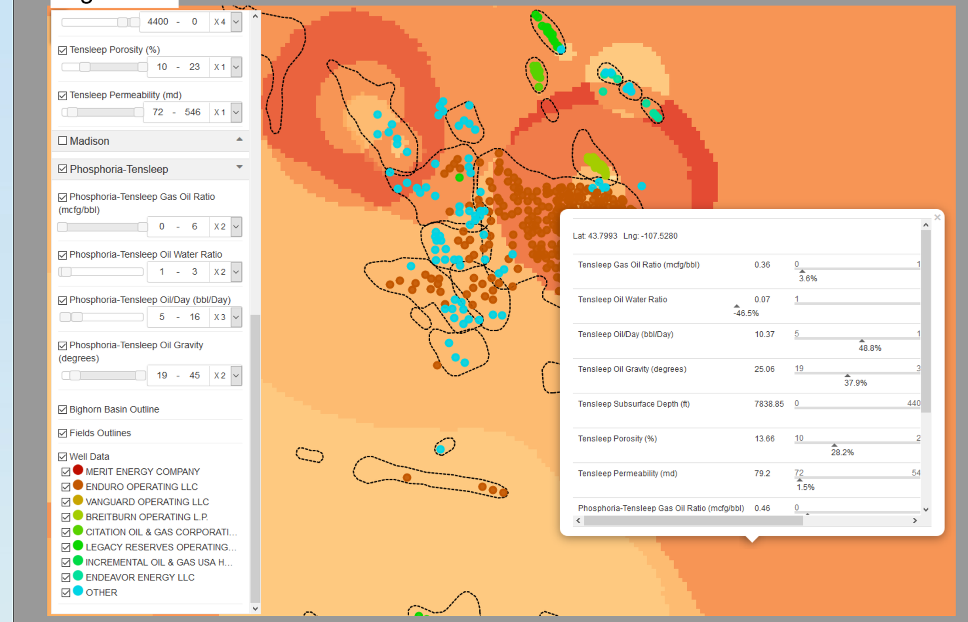
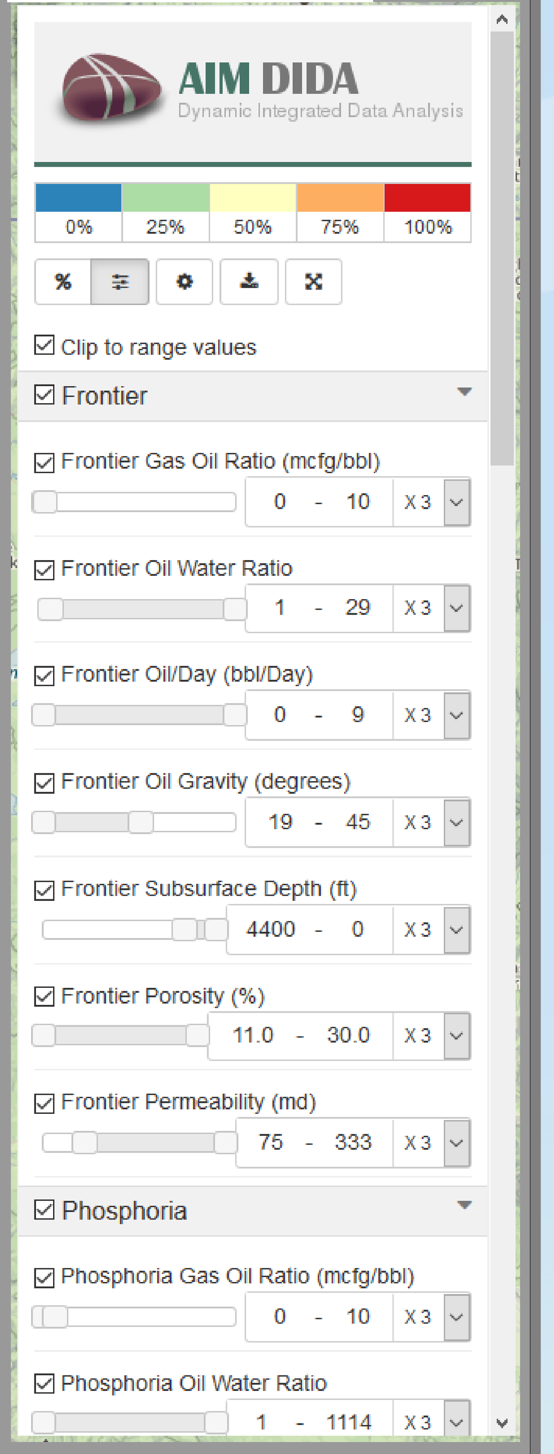


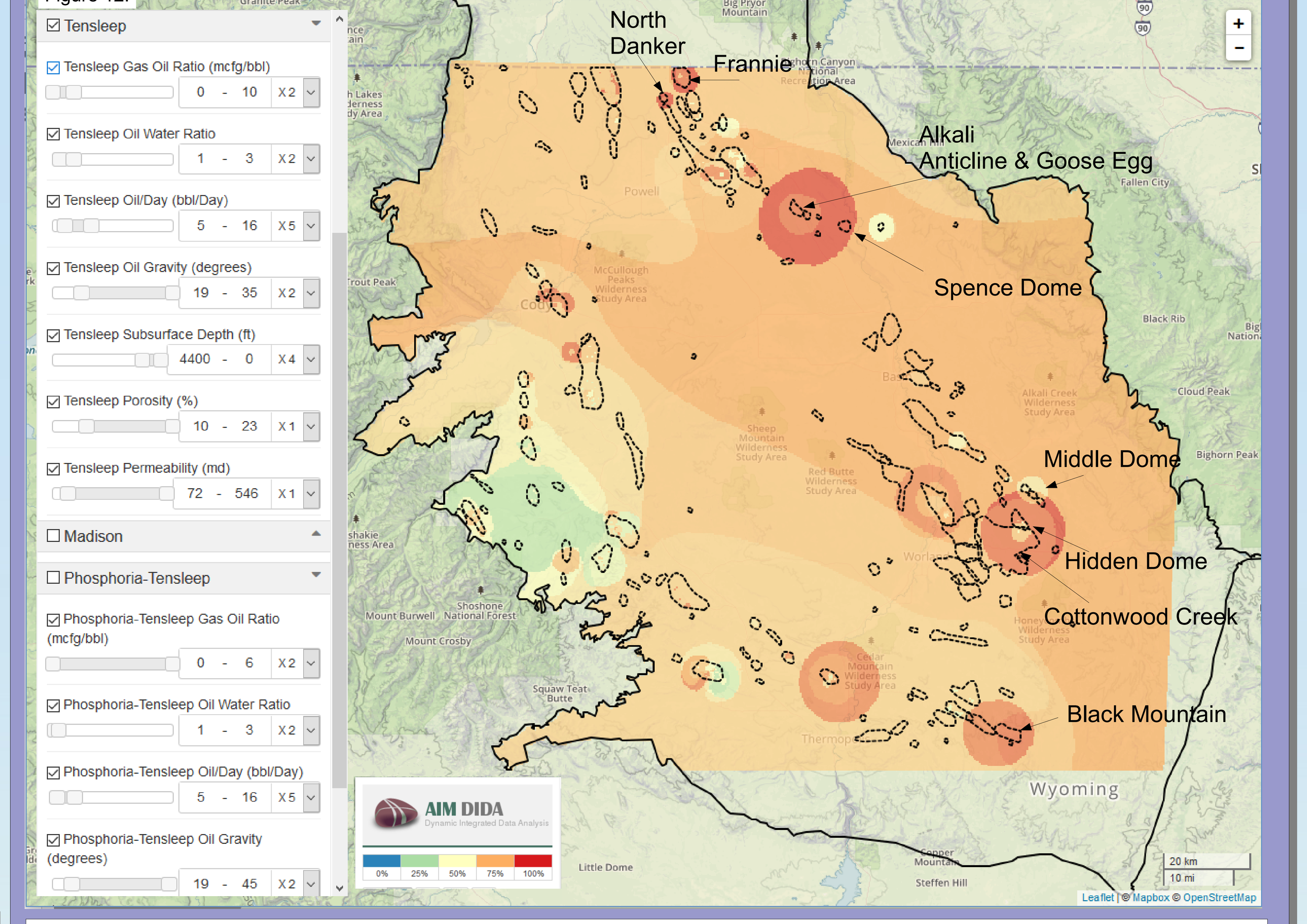
Figure 10: Customizable query:



6. Example Results

Results:
-Dynamic integration of large data sets was successful as screening tool for areas of high potential
-Visualized and selected relative parameter importance
-Provided fast and objective evaluation of mature and data-rich hydrocarbon basin
-Can be implemented by individuals or companies during an early phase of basin evaluation.

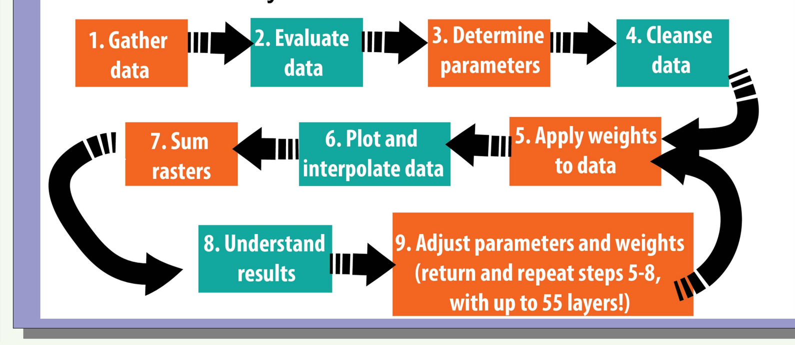
Figure 12:



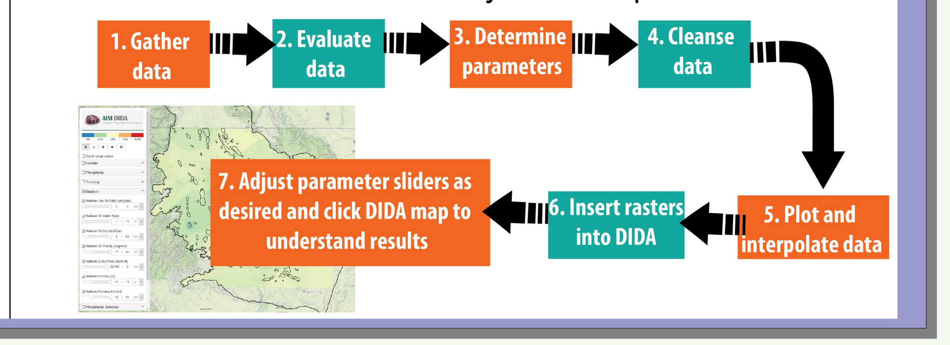
Above (Fig. 12): DIDA Tool model weighted overlay results for Tensleep marginal play. Parameter selection and reasoning is as follows:
- GOR 0-10, the EIA defines light-oil wells as having a ratio of 5-10, and heavy oil wells 0-5 mcfg/Bbl. This study sought marginal oil plays, light and heavy alike.
- Oil:Water Ratio of 1-3. Wells producing more water than oil were more favorable, but wells with significantly more oil than water are questionable data points and were avoided.
- Oil per well per day of 5-16 Bbl to target the strongest marginal producers (marginal wells are defined in Wyoming 15 Bbl oil/day or less).
- API gravity of 19-45 degrees, based on the assumption that most oil produced from this basin falls within this range, so refineries will likely be setup to refine this range of crude qualities.
- 0-4,400' Depth range was determined using production per depth plots, where the greatest producers typically fall within this depth range, and considering the economic benefit to a shallower well.
- Porosity and permeability ranges were chosen favoring greater porosity and permeability, and considering the data ranges that correlate to greatest oil production.
- Phosphoria-Tensleep co-mingled production were included in this model.

The top fields for Tensleep marginal production play are labeled above. These fields are operated by a number of different companies. See live DIDA Tool display for more results

Early version: time intensive

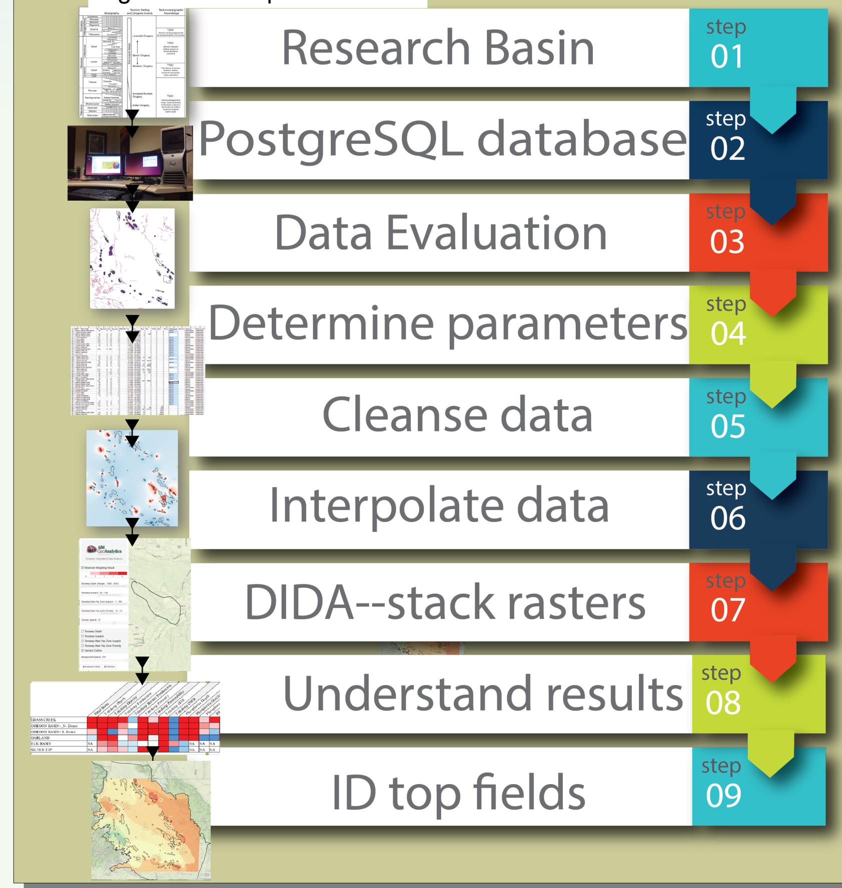


DIDA Tool: Considerably fewer steps



4. Basin Analysis Workflow and Data QC

Figure 7: Example workflow



Evaluating input-data involves steps such as: cross-plot visualization of parameters, investigating differences between reservoirs, plotting or averaging field and reservoir data to search for misplaced data or local outliers, cleansing questionable data.
Left (Fig. 7): Example workflow for basin analysis and DIDA Tool utilization
Below center (Fig. 8): Example 1 of data investigation: production from Tensleep wells by depth to Tensleep top
Below right (Fig. 9): Example 2 of data investigation: average 2015-16 gas, water, oil production by reservoir

Figure 8:

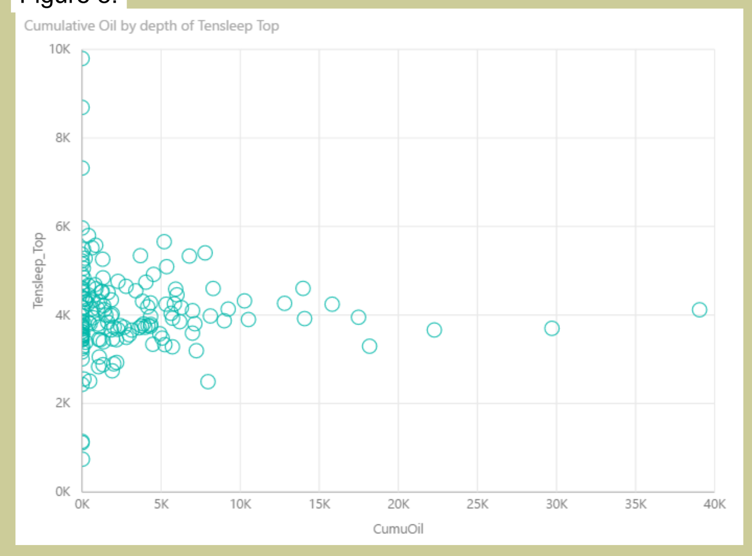


Figure 9:

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6. Example Results Continued

Figure 13:

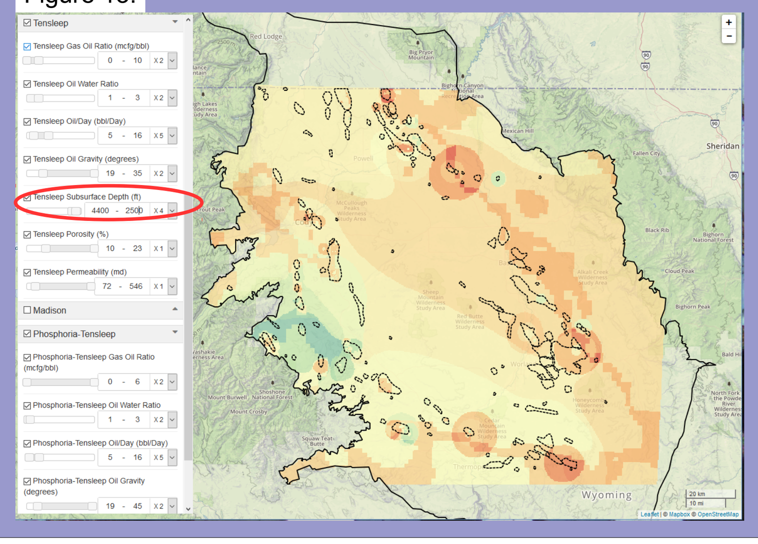
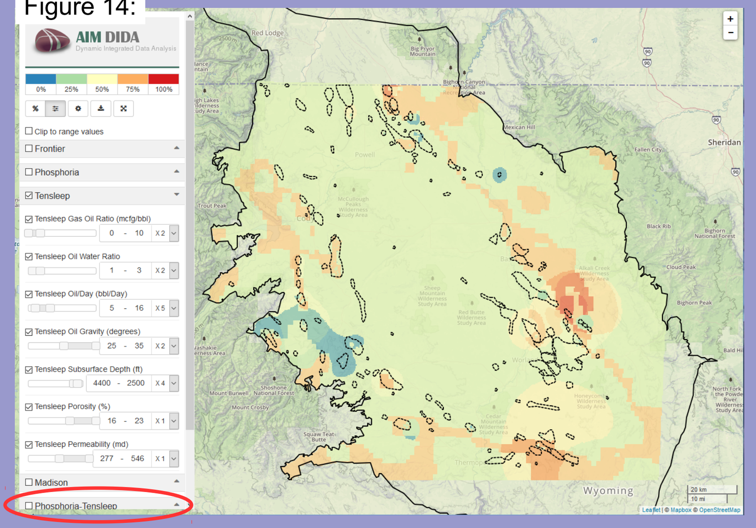


Figure 14:



Figures 13, 14, & 15: Different example marginal Tensleep play DIDA results; DIDA tool parameter changes to Figure 12 query results are circled in red.
Below right (Fig. 16): Early model results evaluating multiple reservoirs and not prioritizing marginal plays. This figure is presented again as direct comparison to marginal Tensleep DIDA case study.

Figure 15:

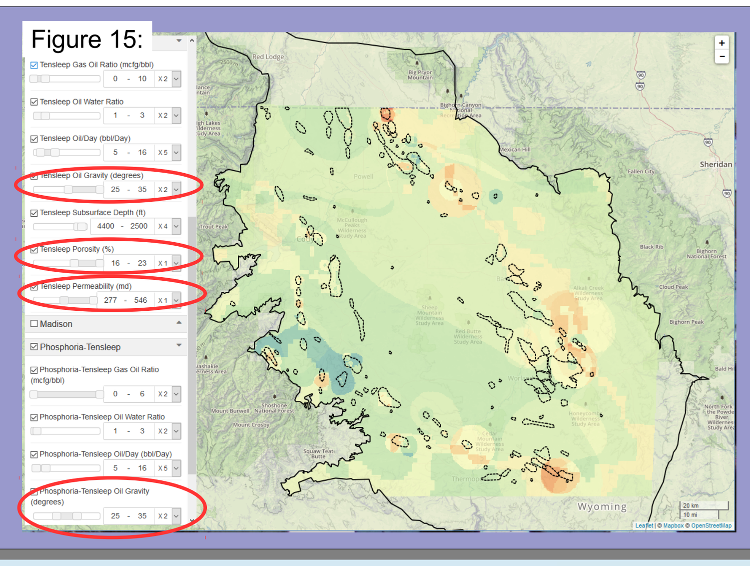
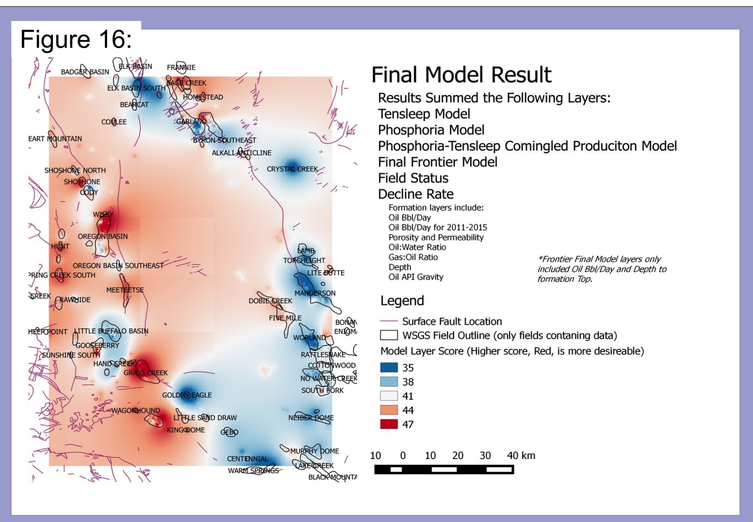


Figure 16:



7. Conclusions

BHB Case Study

- For a marginal Tensleep play, fields on east side of basin appear more favorable than on west side of basin. Frannie, Black Mountain, Spence Dome appear particularly favorable
- Better porosity and permeability data confidence is needed
- Next step would be correlating well logs and investigating individual fields

DIDA Tool

- Successful as screening tool
- Limited by factors such as unknown completions methods
- Data confidence and uncertainty still an issue, e.g. por & perm data limitations, wells reporting little or no water production are suspicious; ease of weighting helps handle this uncertainty
- **start-to-finish comparison of early probability modeling to dynamic modeling shows CONSIDERABLE time savings with DIDA tool**

See accompanying DIDA tool demo

8. References and Acknowledgments

Cardinal, D. F., Miller, T., Stewart, W. W., & Trotter, J. F. (1989). Wyoming Oil and Gas Fields Symposium; Bighorn and Wind River Basins.

Fox, J. E., & Dolton, G. L. (1989). Petroleum geology of the Wind River and Bighorn basins. Wyoming and Montana: US Geological Survey Open-File Report, 87.

Wyoming Oil and Gas Conservation Commission, http://wogcc.state.wy.us/legacywogcce.cfm

Wyoming State Geological Survey http://www.wsgs.wyo.gov/energy/oil-gas-basins

The authors acknowledge Nick Jones at the Enhanced Oil Recovery Institute, (http://www.uwyo.edu/eori/) who answered many questions about the Bighorn Basin and its production history

Related talk “Characterizing spatial deformation patterns in a Laramide Rocky Mountain basin” by Cody Bomberger in Rocky Mountain Tectonics and Stress Regimes session. Monday afternoon.
Related poster “The use of unconventional spatial statistics as a predictive tool in conventional petroleum exploration: A case study from the Bighorn Basin, Wyoming” by Brianna Berg in Tuesday AM poster session