# Regional Mapping of Genetic Intervals in the Almond Formation, Greater Wamsutter Field, Southwest Wyoming: An Iterative Geostatistical Approach to High-Grading Well Locations and Implications for Reserves Bookings*

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See related article, "Almond Formation Lithostratigraphic Genetic Units, Greater Wamsutter Field, Southwest Wyoming: Phase III: From Iterative Geostatistical Approach to High-Grading Well Locations," by Natasha M. Rigg and Jeffrey M. Yarus, Search and Discovery Article #50159 (2009).

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## Abstract

Wamsutter field produces from the Almond formation, a tight gas sand reservoir in the Washakie Basin, and has been, historically, developed as a statistical play with poor correlation to geologic parameters. In order to continue an economic drilling program and accurate reserve estimation and reporting in Greater Wamsutter field, better prediction of reservoir-quality sands is necessary. Geostatistical methods were utilized to improve the geologic geocellular model and high-grade well locations in order to enhance economics in the field and prepare for future increased density spacing.

A pragmatic approach was used to conduct a basin-wide, lithostratigraphic analysis of the Almond Formation within the Washakie Basin, using previous studies, increased well control, and additional Almond core. Further, a unique cross-section analysis was performed using color-filled conductivity, gamma ray, and bulk density logs that were plotted on a single track for each well. Cross-section lines were generated on a closely spaced grid, creating a "pseudoseismic" display, which illuminated flooding surfaces, sands, and coals. Using a Galloway-type approach to genetic stratigraphy, marine flooding surfaces in the middle Main Almond unit were identified and correlated during Phase I of this project. This unique cross section analysis helped to identify eight genetic lithostratigraphic intervals, considerably different from other interpretations.

The total available wells in the field were divided into training and testing sets in order to set up an iterative process for achieving convergence around accurate predictions, using a combination of deterministic and stochastic methods. A series of refinement steps where improvements to the log normalization process, well top correlations, and the GDE maps were performed to allow well locations to be high-graded based on total net sand thickness. The well data were divided into two sets; a training set and testing set. Training wells were used to

create hand-drawn, gross depositional environment (GDE) maps that were used in a collocated cosimulation procedure to ensure the "human" element was included in the model for each interval. Testing wells were used to measure the uncertainty of the final models.

Geostatistical modeling of gross and net sand data proved to be an efficient, cost-effective method to high-grade well locations, given a robust geologic framework. Additionally, the methodology proved valuable in interrogating the data and identifying anomalies, which were either corrected or explained. The result was a reduction in the uncertainty in the geologic framework, and an explanation of the uncertainty that remained. While this methodology has caused Anadarko to internally change its thinking around Wamsutter gas reserves, the company is currently considering how this new model can be used to formally book reserves.

## References


Blakey, Ron, 2001, North American paleogeographic maps: References: Late Cretaceous (85 Ma) (http://jan.ucc.nau.edu/~rcb7/nam.html).

Roehler, H.W., 1988, The Pintail coal bed and barrier bar G – A model for coal of barrier bar - lagoon origin, Upper Cretaceous Almond Formation, Rock Springs Coal Field, Wyoming: U.S. Geological Survey Professional Paper 1398, 60 p.

# Regional Mapping of Genetic Intervals in the Almond Formation, Greater Wamsutter Field, Southwest Wyoming

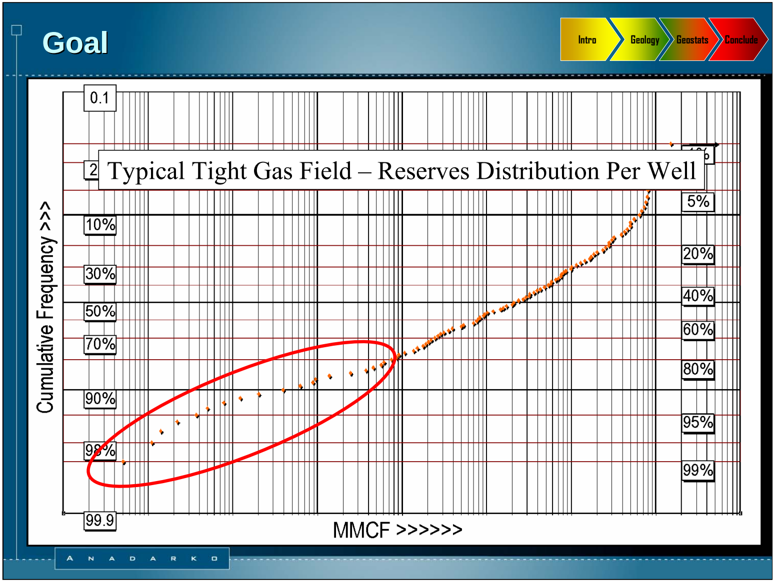
## An Iterative Geostatistical Approach to High-Grading Well Locations and Implications for Reserves Bookings

ANADARKO

*Natasha M. Rigg*
*September, 2009*

# Outline

- **Introduction**
  - *Goals & Objectives*
  - *Iterative Process*
- **Geologic Framework**
  - *Background*
  - *Log Correlations*
  - *{Interpreted} Gross Depositional Environment Isopachs*
- **Geostatistical Model**
  - *{Simulated} Net Sand Isopachs*
  - *Key Improvements (Stage I vs. Stage II)*
  - *Results*
- **Project Results & Conclusions**




***Presenter's Notes:*** Goal is to eliminate sub-economic wells from the drilling program, thereby increasing the average overall.

# SW Wyoming in the Cretaceous

Intro


*Blakey, 2001*

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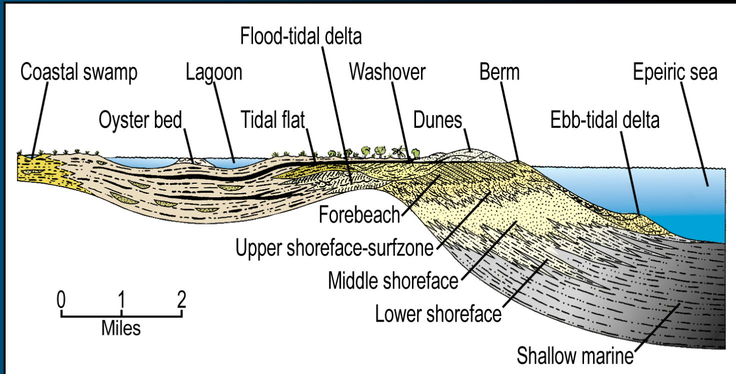
***Presenter's Notes:*** Location of Wamsutter field in relation to the Cretaceous Interior Seaway.

# SW Wyoming in the Cretaceous

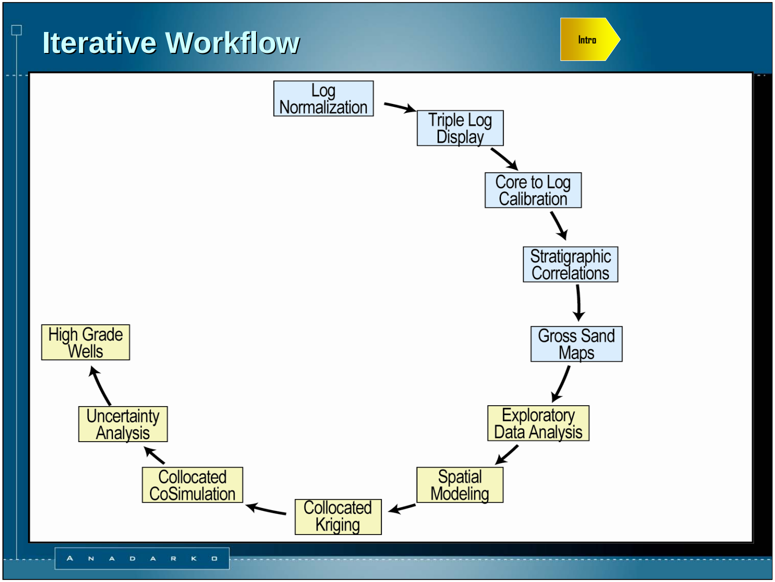
Intro



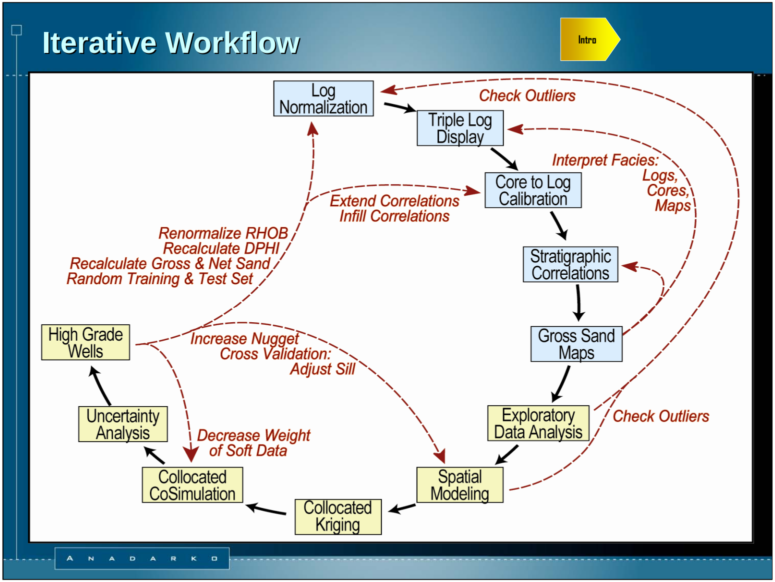

**Modified from Roehler, 1988**

A N A D A R K O

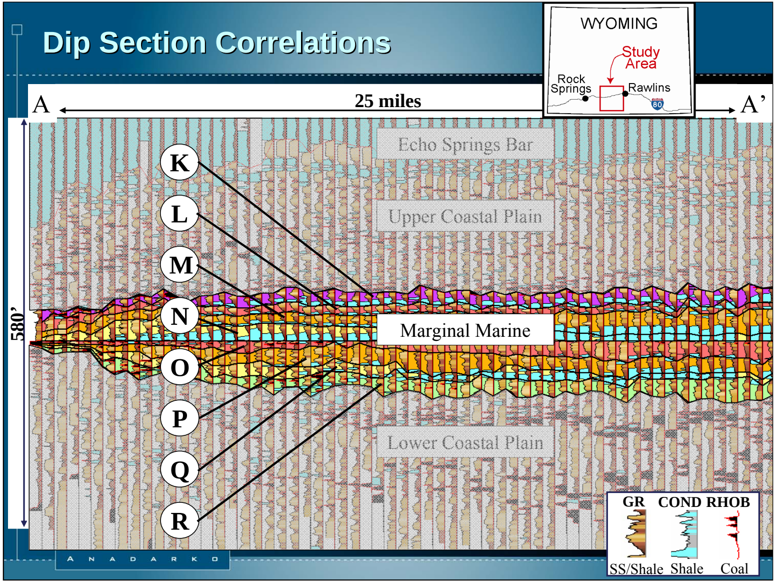
***Presenter's Notes:*** Typical reservoir targets: fluvial channels, foreshore and deltaics.




***Presenter's Notes:*** This shows the ideal workflow that we used in developing the geologic model. The first half is the steps taken to develop the geologic framework, and the last half shows the steps we have taken geostatistically to model data within the geologic framework.




***Presenter's Notes:*** In reality, it is a much more iterative process, as the geostatistical modeling highlights issues with the input data and geologic interpretations. Because of this iterative process, the geostatistical analysis was done in 2 stages. The results of stage I highlighted issues with the input data and interpretation. We went back and adjusted these data (if in error)/interpretations and then remodeled everything during stage II. Before geostatistical analysis took place, we divided the wells into training and testing sets. The training wells are used to create the model; the test wells are used to evaluate how well the model predicts a given property, in this case, net sand.




***Presenter's Notes:*** Though it is difficult to get a good correlation between production and some geologic attribute (due to different vintages of logs, frac styles, etc), we do target higher net sands, making the assumption that thicker net sand will yield higher production. The goal for this project is to better predict thicker net sands and high grade our drilling program accordingly.

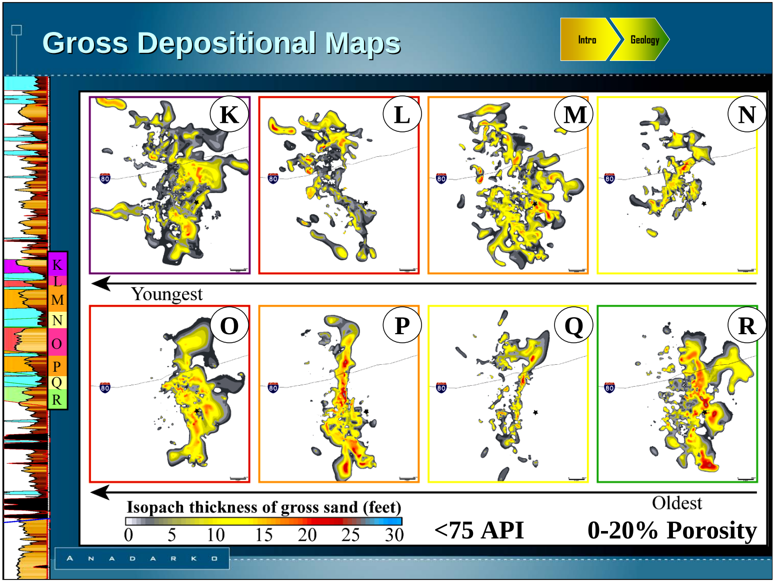
There were several key learnings in this project:

"Postage stamp" analysis, or evaluation of production on offset wells only, isn't good enough. We had to take a step back and look at the field as whole (basin-scale), and develop a much better understanding of the depositional environment.

Pseudoseismic Display: One key tool we used to correlate wells is what we call a "pseudoseismic line". Wells were spaced equidistant apart.

Gamma ray, conductivity, and bulk density logs were overlain on top of each other and their scales adjusted to maximize the visual (correlation) effect. Once we "datumed" on the maximum flooding surface (first identified by Martinsen, 1995), genetic, lithostratigraphic intervals became very evident and were easily correlated.

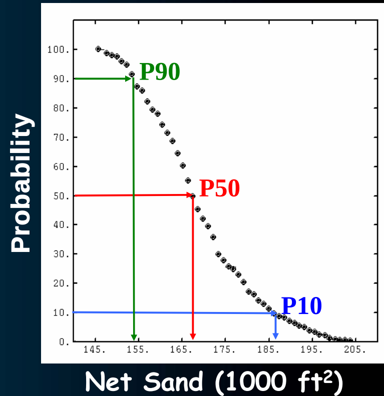
We identified 8 genetic intervals within the middle marginal marine unit of the Almond Formation.




***Presenter's Notes:*** We then made hand-drawn interpreted gross sand maps for these 8 intervals. These gross sand maps were used as soft background data during geostatistical modeling of net sand data. Another key learning was that the process of geostatistical modeling highlighted errors or inconsistencies in the geologic data and/or interpretations. Thus, the iterative process is key!!

# Uncertainty Analysis

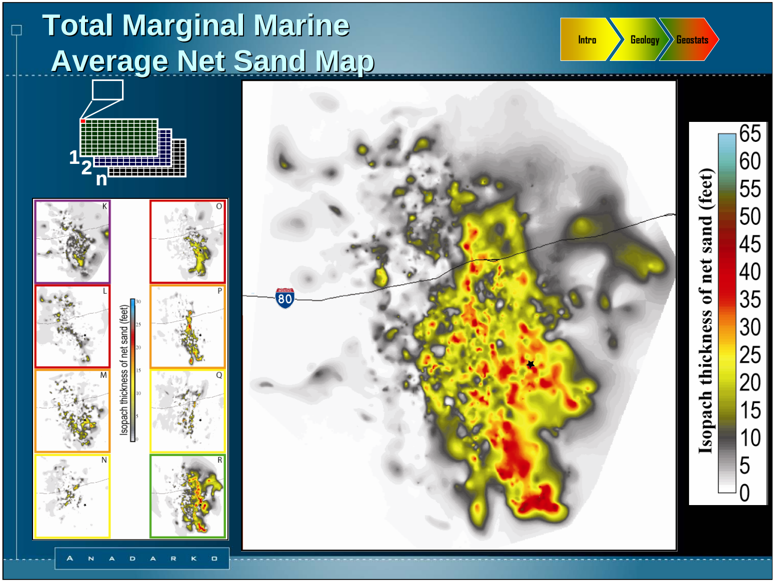
- **Hard Data:**
  - *Net Sand Thickness / Interval*
- **Soft Data:**
  - *Interpreted Gross Sand Maps*
- **Method:**
  - *Collocated cosimulation*
  - *100 realizations/interval*
  - *1800 realizations total*



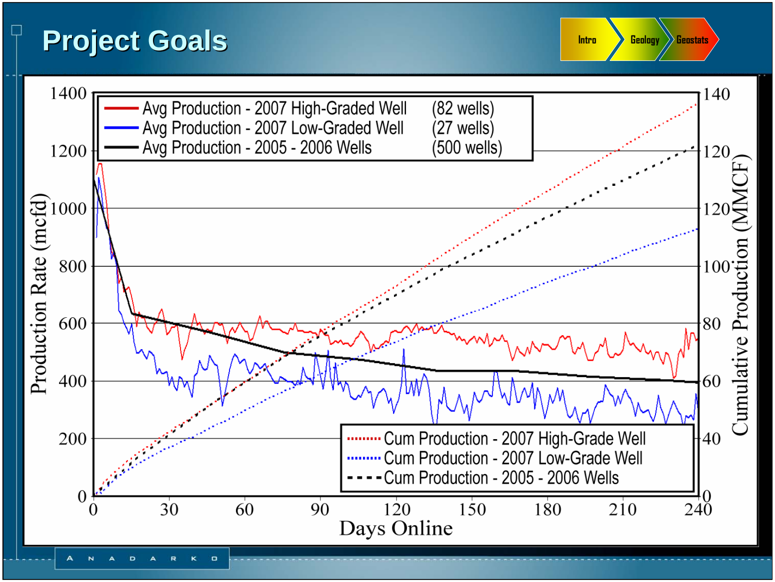



***Presenter's Notes:*** The total net sand is calculated for each realization. The accumulated net sand for each realization is then plotted on a cumulative probability distribution. From here, we can pull out our P10, P50, and P90 maps. These are used in bracketing our uncertainty. For example, the total summed volume from each realization is ranked and now represents a single point on the CPDF. In this case, the attribute is net sand. However, it could be complex formula to derive OOIP. Further, the calculation can be restricted to a polygon or selected portion of the model.

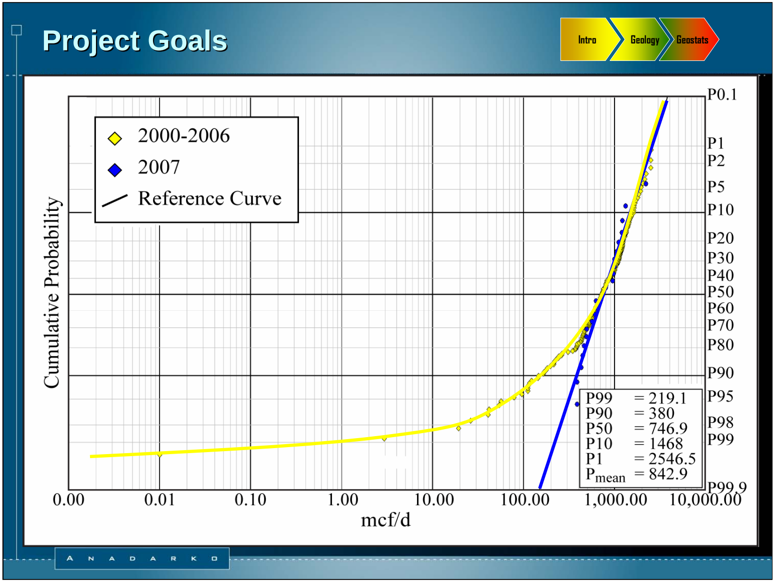
Additionally, from such a CPDF, one could identify the realizations that correspond to the same volume (K and Ø) found for each of the p10, p50, and p90. These realizations could then be upscaled and presented to the simulator.




***Presenter's Notes:*** Because we used the same seed number for the 100 iterations for each of the 8 intervals, we could then add (by seed number) these intervals together, plot up a new CPDF and pull out one particular iteration, in this case, the P50. This map was then used to high grade well locations (both operated and non-operated) for the 2007 drilling year.




***Presenter's Notes:*** These are the results for the non-operated wells for 2007 compared to the non-operated wells from previous years. "High-graded" wells (consented) show higher production when compared to "low-graded" (non-consented), and previous years' wells.




***Presenter's Notes:*** For our operated program, I'm showing the first 30 days IP for the 2007 wells compared to previous years' wells. By high-grading our well locations using our improved geologic & geostatistical model, we have effectively truncated the lower producing wells, increasing our average production for the overall program.

# Conclusions

- **Iterative Process is Key to:**
  - *Improving Overall Understanding of Reservoir*
  - *Improving Geologic Model*

- **Improved Geologic & Geostatistic Model has…..**
  - *Allowed Better Prediction of Net Sand*
  - *Provided Foundation for Further Assessment of Variability in Geology*

- **Allowed Better Reservoir / Drilling Decisions**

# Future Work



- New Petrophysical Model
  - *Upper Coastal Plain*
  - *Middle Marginal Marine*
  - *Lower Coastal Plain*
- Rock typing
- GIIP estimate
  - *Reserves*
  - *Recovery factor*