Reservoir Modeling – An Insider's History of a Key Enabling Technology*

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Abstract

As the capability of computers and software increased and cost significantly decreased in the early 1980’s, it did not take long for geological workstations and reservoir modeling software to become a key enabling technology for the industry. The initial tools included integrated and interactive applications that allowed geologists to generate cross sections, maps, and 3D reservoir property models with relative ease, facilitated by databases that could be easily updated and revised. Early adopters were generally project teams working on large assets with hundreds to thousands of wells for whom the workstation environment provided a clear benefit in terms of efficiency, technical quality, and cross-discipline cooperation. The “cultural” gap between the geoscience and reservoir engineering disciplines began to shrink in the early 1990's as technology improvements enabled easy use of increasingly detailed 3D reservoir property models to be readily up-scaled for the dynamic models used by reservoir engineers to evaluate development options and generate production forecasts. The 1990’s also witnessed the rapid acceptance of the use of a variety geostatistical algorithms (e.g., kriging, conditional simulation, multiple-point modeling, object-based modeling, and process-mimicking modeling) to populate the increasing detailed reservoir models. The ability to generate very large and very detailed reservoir models gave rise to the still unresolved issue of how much model complexity is actually useful – an issue variously referred to as “fit-for-purpose” modeling or, somewhat divisively, as “Gilligan vs. Frankenstein” modeling. The incorporation of a variety of geostatistical algorithms also led to significant improvements in the industry’s assessment and use of uncertainty in reservoir development decisions. By the early 2000’s the reservoir modeling “toolkit” moved largely from proprietary software to vendor-provided software. This change significantly improved cooperation and decision making among private and national oil companies. In less than four decades, the industry reservoir modeling capability went from reservoir

models with a few thousand grid cells with dimensions on the order of hundreds to thousands of feet to today's reservoir models that may have up to a few billion cells (the so called "giga-cell" models) with grid dimensions of a few tens of feet or smaller.

Selected References

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Reservoir Modeling – An Insiders History of a Key Enabling Technology

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20-23 May 2018 • Salt Lake City, Utah
ACE 2018
ANNUAL CONVENTION & EXHIBITION

ACE 101: Bridging Fundamentals and Innovation

Phase 1 - Initial Efforts

- Early/Mid-1980s
  - Interactive seismic interpretation software became “standard” tool in the exploration departments of major oil companies
  - Provided a competitive advantage to major oil companies; proprietary systems
  - High capital cost for CPU and graphic display terminals
  - Significant maintenance costs for both hardware and software
  - Initial efforts to broaden appeal and support led to simple well log displays, grid-based modeling of reservoir data and production data “time-lapse” movies (Griesbach et al, 2006)

Phase 1 - Initial Efforts

- Interactive Graphics Enhance Reservoir Characterization (Griesbach et al., 1986)

Left – Map showing wells with well logs
Right – Well log display (caliper and density logs)

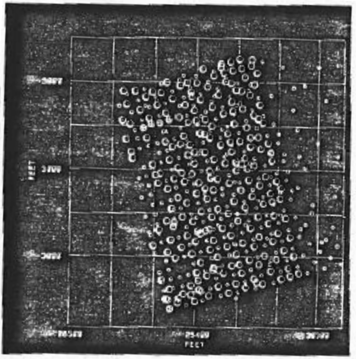


Figure 2: *Base map of the wells used for interactive interpretation in the study. Red circles mark well locations where digitized log curves have been loaded to a data base. Red circles with X's mark the wells with logs shown in Figure 3. Green circles mark additional well locations.*

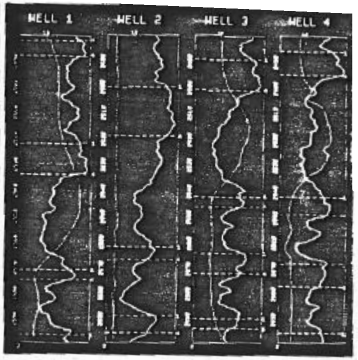


Figure 3: *Bulk density and caliper logs from four west-east wells in the study area showing bump and marker tie capabilities. The density logs (in blue) range from 2 to 3 grams/cc and the caliper logs range from 7 to 15 inches. All the logs are "hung" on the top of the BC sand (blue marker 4).*

Phase 1 - Initial Efforts

- Interactive Graphics Enhance Reservoir Characterization (Griesbach et al., 1986)

Left – Reservoir lithology model based on bulk density
Right – Model lithology key

Reservoir model generated using simple interpolation by depth (iso-depth model)

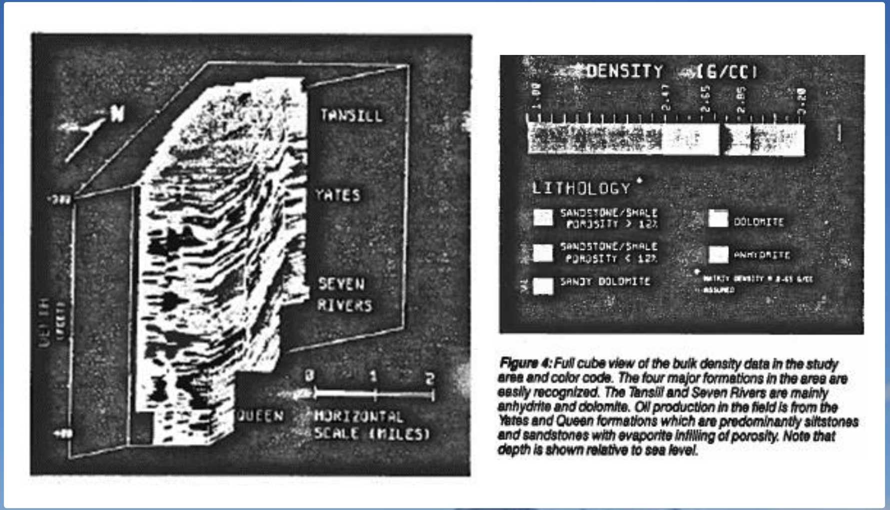


Figure 4: Full cube view of the bulk density data in the study area and color code. The four major formations in the area are easily recognized. The Tansill and Seven Rivers are mainly anhydrite and dolomite. Oil production in the field is from the Yates and Queen formations which are predominantly siltstones and sandstones with evaporite infilling of porosity. Note that depth is shown relative to sea level.

Phase 1 - Initial Efforts

- Interactive Graphics Enhance Reservoir Characterization (Griesbach et al., 1986)

Left – Extracted cross section from the iso-depth reservoir lithology model
Right – Extracted cross section from a model that constructed on a reference marker (iso-relative depth model)

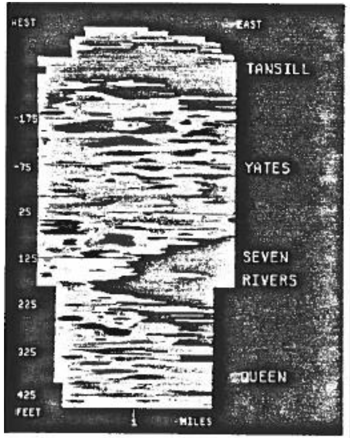


Figure 7: A vertical slice of the bulk density cube along dip. An overlay shows the depth relative to sea level and the formation names.

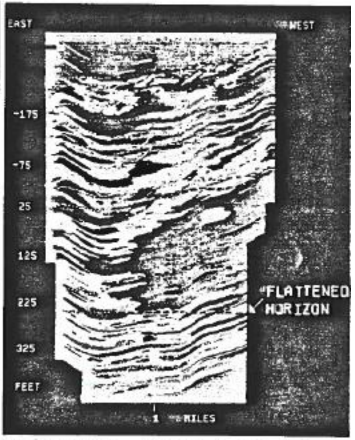


Figure 8: A vertical slice of the bulk density cube that has been "hung" on a marker. Such a display is similar to a well log cross section which has been constructed with depths relative to a marker.

Phase 1 - Initial Efforts

- Interactive Graphics Enhance Reservoir Characterization (Griesbach et al., 1986)

Left – “Time Slice” extracted from a production data model (iso-time) showing BOPD for May, 1980

Right – Vertical slice from an iso-depth caliper data model (dark areas highlight likely washouts)

Figure 5: A time slice of the production history cube for May, 1980. Blue colors represent 0 to 10 barrels per day, greens represent 10 to 30 barrels per day, yellows represent 30 to 50 barrels per day, and oranges represent 50 to 100 barrels per day. The daily oil production was averaged over each month to avoid daily fluctuations in production. An overlay shows the well locations (dots) and section boundaries (solid lines). Each section is one square mile.

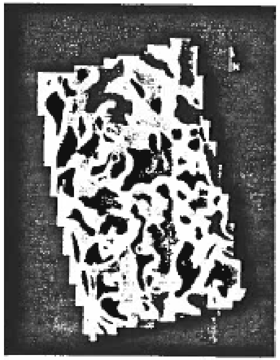
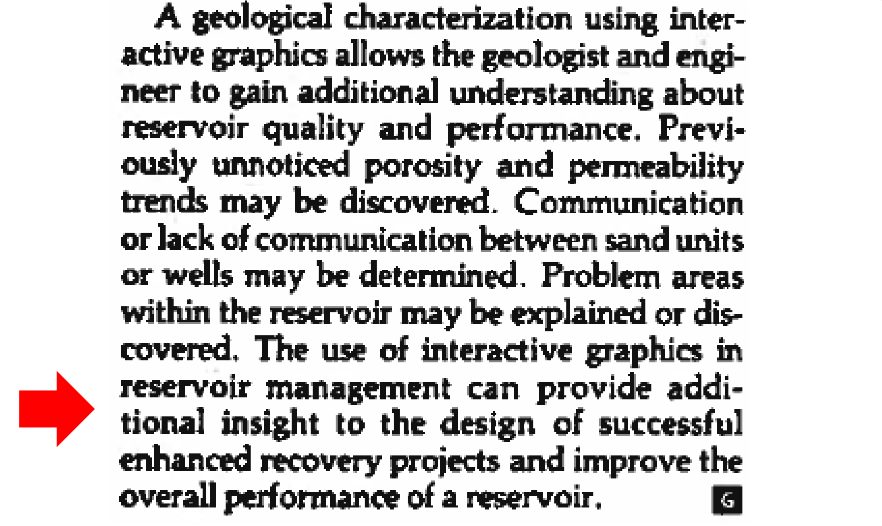


Figure 10: A vertical slice of the caliper cube highlighting areas where washouts have occurred. Light blue represents areas where the caliper reading is greater than nine inches and dark blue represents a caliper reading of less than nine inches. Note that the majority of washouts have occurred in the more friable Yates formation.

Phase 1 - Initial Efforts

- Interactive Graphics Enhance Reservoir Characterization (Griesbach et al., 1986)

From the author's summary (GEOBYTE, Spring 1986)



A geological characterization using interactive graphics allows the geologist and engineer to gain additional understanding about reservoir quality and performance. Previously unnoticed porosity and permeability trends may be discovered. Communication or lack of communication between sand units or wells may be determined. Problem areas within the reservoir may be explained or discovered. The use of interactive graphics in reservoir management can provide additional insight to the design of successful enhanced recovery projects and improve the overall performance of a reservoir.

Phase 1 - Initial Efforts

- Production company offices (including field offices) were intrigued by the potential applications of interactive graphics, particularly for fields with many wells
- But, the “workstation” cost was too high, the reservoir models were geologically “simple”, and there was not an easy way to build/update the underlying geological and production “data base”

Phase 2 – Production Workstation

- Corporate merger resulted in a small group of production and reservoir geology staff able to focus on developing a “Production Workstation” with the following constraints:
  - Workstation capital cost less than $100K
  - Technical support and maintenance cost no more than 10-20% of that devoted to the typical seismic interpretation workstation
  - Effective and easy to maintain “database” that could easily be updated as new wells were added to a field or the production data was updated monthly
  - Improved geological constraints, particularly for reservoir models that the engineers soon realized could be the basis for their simulation models

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Phase 2 – Production Workstation

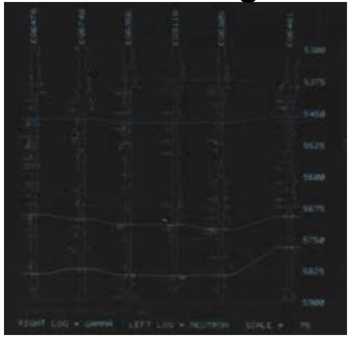
- The software eventually became known as “PROGRESS” – a mash-up of production, graphics, geology, reservoir engineering, and simulation
- PROGRESS provided the user with the ability to interactively pick and correlate formation markers, generate geological and production maps, surface and cross sections from an iso-depth 3D model or from a 3D model generated using a novel Surface Aided Contouring Method (SACM)

Bloom, J. R. and Meddaugh, W. S., 1988. Chevron's Production Workstation: Geoscience Information Society (GSA) Proceedings, v. 19, p. 191-201.

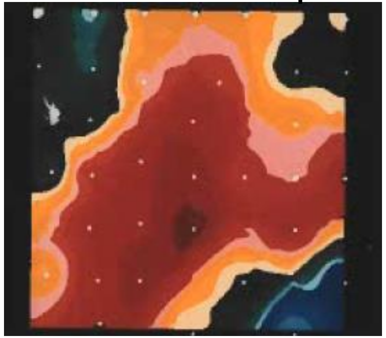
Phase 2 – Production Workstation

- PROGRESS provided basic geological applications in a fully interactive environment

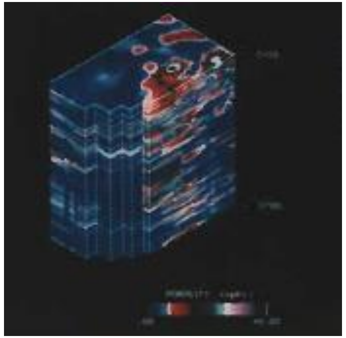
Well Logs



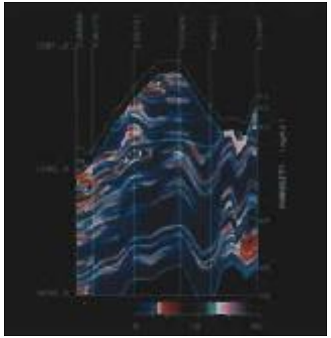
Structure Map



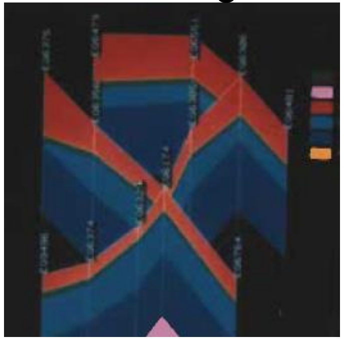
3D Model



3D Model Slice

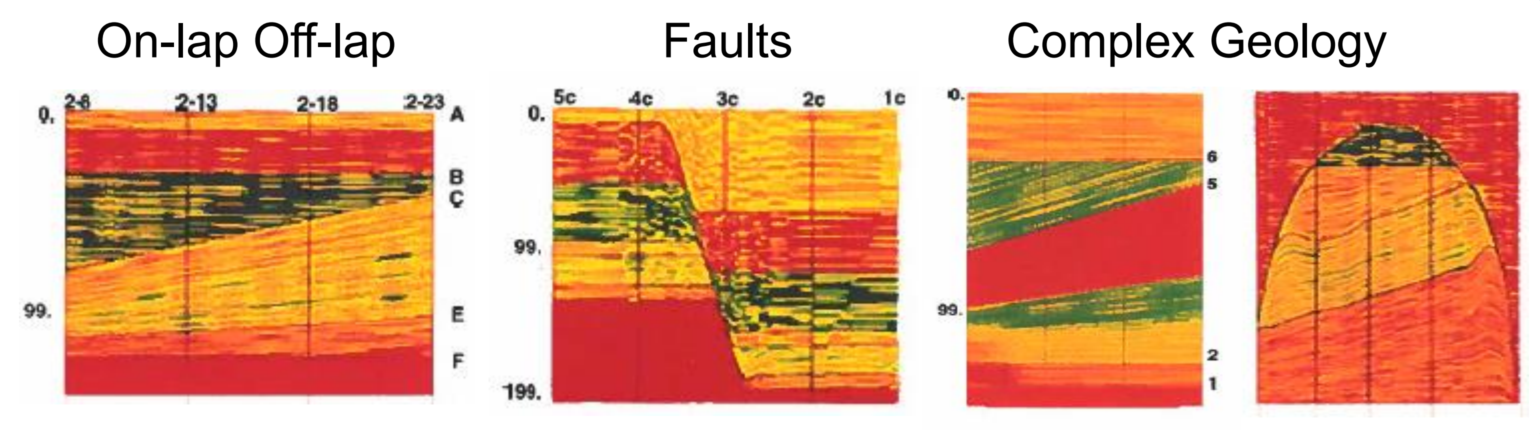


Fence Diagram



Phase 2 – Production Workstation

- SACM enabled geologists to build geologically constrained reservoir property models. Previous iso-depth models models became “obsolete”.



On-lap Off-lap

Faults

Complex Geology

Bloom and Meddaugh, 1988

Phase 2 – Production Workstation

- Rapid Deployment
  - Initial deployment to a field office included a “free” reservoir database build and training using local data
  - Low capital and maintenance costs
  - Easy monthly/quarterly database updates
  - Used by geologists and engineers; increased collaboration
  - SACM facilitated reservoir simulation model construction that better “honored” the geology
  - Software for Commercial Workstations and PC platforms appear from several vendors and begin to rapidly replace proprietary platforms in mid/late 1980’s and early 1990’s

Phase 3 – Geostatistics Arrives

- Drivers
  - Geostatistical techniques initially based on the semivariogram provided additional improvement and ease in building reservoir models that honor the “geology”
  - Geostatistical model building software is developed (company proprietary in the late 1980s, early 1990s; emergence of industry/university consortia and, eventually, commercial software on workstation and PC platforms). The GEOLITH program is an example (Araktingi et al., 1993).
  - Reservoir simulation becomes routine for many reservoir decision workflows, particularly when the impact of reservoir uncertainty became a “required” aspect of project decisions

Phase 3 – Geostatistics Arrives

- Drivers
  - Model building becomes “easy” to use due to intuitive graphical interfaces and incorporation of simple links to reservoir simulation (with and without upscaling), incorporation of seismic data, and generate multiple models for uncertainty analysis

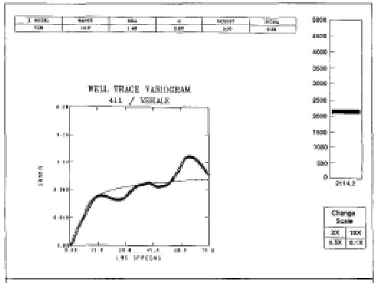


Fig. 8—Isotropic variogram being fit interactively with slide bar.

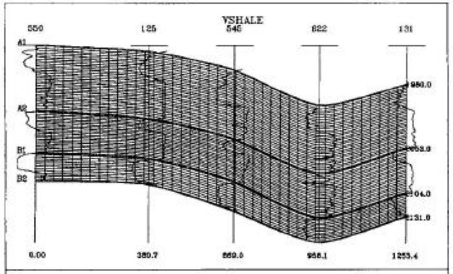
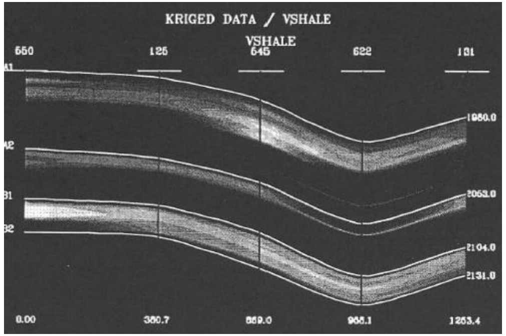


Fig. 3—Cross section showing stratigraphic estimation/simulation grid.

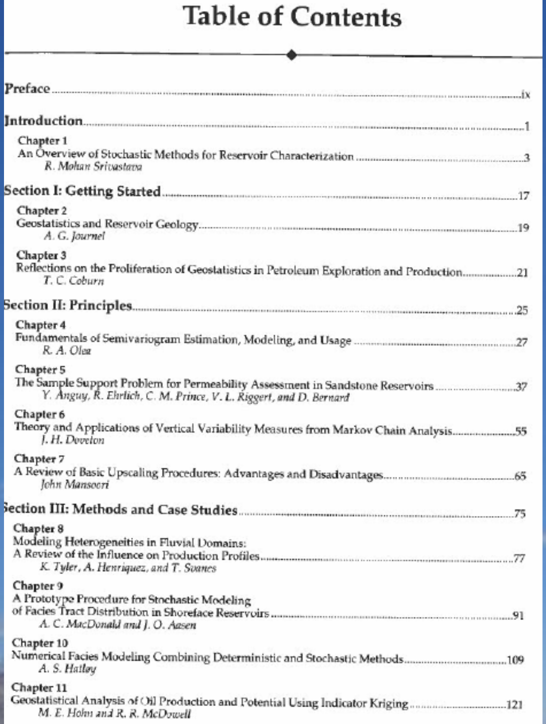


GEOLITH: An Interactive Geostatistical Model Application, Araktingi et al., 1993

Phase 3 – Geostatistics Arrives

- Drivers (continued)
  - Important and well attended meetings including AAPG, SPE, and EAGE sponsored meetings and publications such as
    - Stochastic Modeling and Geostatistics: Principles, Methods, and Case Studies, Volume 1 (edited by Yarus and Chambers, 1994)
    - Stochastic Modeling and Geostatistics: Principles, Methods, and Case Studies, Volume 2 (edited by Coburn, Yarus, and Chambers, 2006)
    - International Geostatistics Congress meetings
    - Other technical society meetings including the EAGE, SPE, and SEG

The Pioneers: Table of Contents from *Stochastic Modeling and Geostatistics: Principles, Methods, and Case Studies, Volume 1* (1994)



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Phase 4 – Geostatistics is a “Standard” Reservoir Modeling Tool in the Industry

- Variety of methods and workflows, including
  - Point-based methods
  - Object-based methods
- Variety of input data
  - Data integration (well log, core, seismic, outcrop, production)
  - Uncertainty assessment and “quantification”
- Variety of commercial software products running on a variety of computing platforms

Closing Comment - 1

- From a developer/user perspective, the new digital platform and tools enabled better, faster, and more robust reservoir modeling using a variety of input data (geological, geophysical, and engineering)
- Shift from a “paper” platform to a paper-less digital platform decreased data or interpretation “intimacy” as the comments and questions often “scribbled” on well logs and maps disappeared

Closing Comment - 2

- Gilligan vs. Frankenstein Models
  - *“As the amount of detail in a scenario increases, its probability can only decrease steadily, but its representativeness and hence its apparent likelihood may increase. The reliance on representativeness, we believe, is a primary reason for the unwarranted appeal of detailed scenarios and the illusory sense of insight that such constructions often provide”*
  - From Tversky and Kahneman (1982) as quoted in Bratvold and Begg (2010) in their book, *Making Good Decisions*

Thank You