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Uncertainty in Reservoir Characterization and Modeling. S. Geiger, M.J. Blunt, P. Corbett, F. Doster, M. Jackson (Eds.), Springer 2024

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Abstract. This book review evaluates Uncertainty in Reservoir Characterization and Modeling, a comprehensive and technically rigorous volume that underscores the indispensable role of uncertainty quantification (UQ) in reservoir engineering. As subsurface resource management grows increasingly complex amid dwindling reserves and environmental scrutiny, the need for robust reservoir models becomes paramount. The book systematically explores key domains of uncertainty—including geological, geophysical, petrophysical, flow modeling, and history matching—while emphasizing integrated, multidisciplinary workflows. It also delves into decision-making frameworks under uncertainty, highlighting probabilistic approaches such as Monte Carlo simulations and stochastic optimization. A major strength of the book lies in its balanced theoretical and practical approach, enhanced by expert contributions and detailed mathematical formulations. While the discussion of emerging technologies such as machine learning is promising, expanded coverage on environmental applications, geomechanics, and software tools would further enrich its value. Despite minor gaps, the book succeeds in presenting uncertainty not as a hindrance but as a manageable dimension in predictive modeling and operational strategy. This review concludes that the book is an essential reference for researchers, students, and practitioners seeking to navigate the uncertainty-laden landscape of modern reservoir management with greater confidence and clarity.
Keywords. Uncertainty Quantification; Reservoir Modeling; Subsurface Resource Management.
JEL. Q32; Q40, C63.
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Book Review

In the complex realm of subsurface resource management, particularly within the oil and gas industry, the ability to accurately characterize and model reservoirs is paramount. However, the inherent heterogeneity of subsurface formations and the limitations of data acquisition inevitably lead to significant uncertainties. These uncertainties can have profound implications for reservoir performance prediction, production optimization, and economic viability. "Uncertainty in Reservoir Characterization and Modeling" tackles this crucial issue head-on, offering a comprehensive exploration of the methodologies and technologies employed to quantify and manage uncertainty in reservoir engineering.

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The book's significance is underscored by the increasing demand for robust and reliable reservoir models in an era of dwindling resources and heightened environmental concerns. Effective uncertainty quantification is no longer a luxury but a necessity for making informed decisions and mitigating risks. This book serves as a vital resource for researchers, practitioners, and students seeking to navigate the complexities of reservoir modeling and decision-making under uncertainty.

Unpacking the Layers of Uncertainty: A Multifaceted Approach

The book adopts a multifaceted approach to uncertainty quantification, encompassing a wide range of topics, including:

- Geological uncertainty: Addressing the inherent variability of subsurface formations.
- Geophysical uncertainty: Exploring the limitations of seismic and other geophysical data.
- Petrophysical uncertainty: Examining the challenges of estimating rock properties from well logs and core data.
- Flow modeling uncertainty: Investigating the complexities of simulating fluid flow in porous media.
- History matching uncertainty: Analyzing the challenges of reconciling model predictions with production data.
- Decision-making under uncertainty: Exploring the use of probabilistic methods for risk assessment and optimization.

This comprehensive coverage ensures that readers gain a holistic understanding of the various sources of uncertainty and the methodologies used to address them.

A Detailed Exploration of Key Themes:

- Geological Uncertainty: The Foundation of Reservoir Modeling:

o Geological uncertainty stems from the inherent variability of subsurface formations, including facies distribution, fault patterns, and stratigraphic architecture. The book delves into various geological modeling techniques, such as object-based modeling, process-based modeling, and multiple-point statistics, which are used to capture this variability. It also examines the use of geostatistics to quantify spatial uncertainty and generate multiple realizations of geological models. The importance of integrating geological knowledge with geophysical and petrophysical data is emphasized throughout this section. The book does a good job of showing how different depositional environments effect the uncertainty.

- Geophysical Uncertainty: Interpreting the Subsurface Signals:

o Geophysical data, particularly seismic data, plays a crucial role in reservoir characterization. However, the interpretation of geophysical data is inherently uncertain due to limitations in data resolution, noise, and non-uniqueness. The book explores the various sources of geophysical uncertainty and discusses techniques for quantifying and mitigating them. It examines the use of seismic inversion, seismic attributes, and geomechanical modeling to improve the accuracy of subsurface

interpretations. The chapters regarding the use of 4D seismic are very informative.

- Petrophysical Uncertainty: Unraveling Rock Properties:

o Petrophysical properties, such as porosity, permeability, and saturation, are essential for reservoir performance prediction. However, the estimation of these properties from well logs and core data is subject to significant uncertainties. The book discusses the various sources of petrophysical uncertainty and explores techniques for quantifying and reducing them. It examines the use of stochastic petrophysical modeling, Bayesian inference, and machine learning to improve the accuracy of petrophysical estimations. The book also discusses the importance of upscaling petrophysical properties from core and log scales to reservoir scales.

- Flow Modeling Uncertainty: Simulating Fluid Dynamics:

o Flow modeling is used to simulate fluid flow in porous media and predict reservoir performance. However, flow models are subject to uncertainties arising from geological heterogeneity, petrophysical variability, and numerical approximations. The book explores the various sources of flow modeling uncertainty and discusses techniques for quantifying and managing them. It examines the use of stochastic flow modeling, ensemble Kalman filters, and reduced-order models to improve the accuracy of flow simulations. The impact of relative permeability and capillary pressure uncertainty is also discussed.

- History Matching Uncertainty: Reconciling Models with Reality:

o History matching is the process of adjusting reservoir model parameters to match observed production data. However, history matching is inherently non-unique, meaning that multiple model realizations can match the observed data. The book explores the challenges of history matching under uncertainty and discusses techniques for quantifying and reducing the uncertainty associated with history-matched models. It examines the use of ensemble-based history matching, Bayesian history matching, and machine learning to improve the accuracy and efficiency of history matching.

- Decision-Making Under Uncertainty: Navigating Risk and Optimizing Value:

o The ultimate goal of uncertainty quantification is to support informed decision-making and optimize reservoir management. The book explores the use of probabilistic methods, such as decision trees, Monte Carlo simulation, and stochastic optimization, to assess risks and evaluate alternative development scenarios. It also discusses the importance of integrating uncertainty quantification into the decision-making process and communicating uncertainty to stakeholders. The book does a good job of explaining the economic impact of uncertainty.

Strengths That Elevate This Work:

- Expert Authorship: The book benefits from contributions by leading experts in the field, ensuring a high level of technical accuracy and insightful analysis.
- Balanced Theoretical and Practical Approach: The book strikes a balance between theoretical concepts and practical applications, making it accessible to both researchers and practitioners.
- Emphasis on Integrated Workflows: The book emphasizes the importance of integrated workflows that combine geological, geophysical, petrophysical, and flow modeling techniques.
- Focus on Emerging Technologies: The book incorporates discussions of emerging technologies, such as machine learning and data analytics, which are transforming the field of reservoir characterization and modeling.
- Strong Mathematical Rigor: The book backs up its claims with strong mathematical equations, and explanations.

Areas for Potential Expansion:

- Integration of Machine Learning: While the book touches upon machine learning, a more in-depth exploration of its applications in reservoir uncertainty quantification would be beneficial.
- Environmental Considerations: With increasing environmental concerns, a discussion of uncertainty quantification in the context of carbon capture and storage (CCS) and geothermal energy would be valuable.
- Geomechanics Integration: While mentioned, a more detailed section on the integration of geomechanics into uncertainty modelling would be very useful.
- Software and Tooling: Providing more information regarding available software, and open source tools would be very useful for readers.
- Case Studies: While the book is very informative, more detailed case studies would increase the books practical value.

Conclusion: A Cornerstone Resource for Reservoir Engineering

"Uncertainty in Reservoir Characterization and Modeling" stands as a cornerstone resource for anyone seeking to understand and manage uncertainty in reservoir engineering. Its comprehensive coverage, expert authorship, and balanced approach make it an indispensable guide for researchers, practitioners, and students. By providing a deep dive into the various sources of uncertainty and the methodologies used to address them, this book empowers readers to make more informed decisions and mitigate risks in the complex world of subsurface resource management. As the demand for reliable reservoir models continues to grow, this book will undoubtedly play a vital role in shaping the future of the industry.

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