British Journal of Earth Sciences Research, 14(1),44-72, 2026
Print ISSN: 2055-0111 (Print)
Online ISSN: 2055-012X (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Operationalizing Reservoir Architectural Element Re-Definition as a Decision-Control Mechanism in Mature Deltaic and Turbidite Fields

Edidiong Edidiong-Umoh
M.Sc Petroleum Geosciences, University of Manchester

doi: https://doi.org/10.37745/bjesr.2013/vol14n14472 Published January 31, 2026

Citation: Edidiong-Umoh E. (2026) Operationalizing Reservoir Architectural Element Re-Definition as a Decision-Control Mechanism in Mature Deltaic and Turbidite Fields, *British Journal of Earth Sciences Research*, 14(1),44-72

ABSTRACT: *Mature deltaic and turbidite reservoirs represent critical hydrocarbon assets globally, yet their management is persistently challenged by declining production efficiency, rising subsurface uncertainty, and static geological models that progressively diverge from observed dynamic behavior. Conventional reservoir characterization workflows, including those structured within the Reservoir Management Maturity Model (RM3) framework, typically treat architectural element definitions—the fundamental building blocks of geocellular models—as fixed inputs established during field appraisal and preserved through subsequent model updates. This practice results in "frozen" geological frameworks that lose epistemic flexibility, leading to systematic static-dynamic mismatch, uncontrolled volumetric uncertainty, and suboptimal infill well placement decisions. The chronic failure to operationalize architectural reinterpretation as an active decision variable represents a critical gap in mature field value optimization methodology.This study presents and validates a novel, structured workflow that operationalizes reservoir architectural element re-definition as a formal decision-control mechanism within mature field static modeling practice. The methodology comprises five integrated stages: (1) baseline model audit identifying systematic performance anomalies symptomatic of architectural misconception; (2) data-driven reinterpretation integrating seismic geomorphology, sedimentological reanalysis, and production diagnostics to propose revised element boundaries; (3) static model re-population implementing revised architectural frameworks within geocellular constructs; (4) dynamic calibration discriminating between competing interpretations through history matching; and (5) decision-control formalism translating narrowed uncertainty into quantified infill well rankings and investment sanction criteria. The workflow is demonstrated through application to two anonymized offshore assets: a wave-influenced deltaic reservoir (Asset D, Niger Delta analogue) and a confined turbidite channel-lobe system (Asset T, deepwater Gulf of Mexico analogue), both characterized by 15–28 years production history and legacy static models constructed under initial appraisal-phase data constraints. Application of the workflow to Asset D achieved 60% reduction in Original Oil in Place uncertainty span (P90-P10 range narrowed from 91% to 36% relative to P50), 74% reduction in Connected Static Volume uncertainty for* *candidate infill locations, and 46% improvement in history match quality without geologically implausible parameter adjustments. Critically, architectural reinterpretation—distinguishing distributary channel from mouth bar elements using integrated seismic-core-dynamic evidence—directly enabled sanction of Well D-44, which was ranked 9th under legacy interpretation but elevated to 2nd rank under revised framework. Well D-44 delivered 3.21 MMstb cumulative production over 66 months, tracking within 6% of revised model forecasts and generating $18.2 million incremental net present value. Across both study assets, the workflow identified seven previously unrecognized infill opportunities, collectively representing 12.4 MMstb incremental accessible resources, with four wells drilled to date achieving average forecast accuracy within ±12%. This study demonstrates that systematic architectural element re-definition, conducted through disciplined integration of existing datasets rather than new data acquisition, functions as a powerful decision-control mechanism that narrows uncertainty, improves model predictiveness, and directly governs capital allocation confidence in mature clastic reservoirs. The methodology transforms static geological models from passive knowledge repositories into active decision-control systems, providing transferable value to hydrocarbon portfolio optimization and emerging subsurface energy transition applications including CO_2 storage site characterization and geothermal resource assessment.*

KEYWORDS: reservoir architectural elements, mature field revitalization, static-dynamic model integration, seismic geomorphology, decision-control mechanism, reservoir management maturity model (RM3), uncertainty quantification, deltaic reservoirs, turbidite systems, infill well optimization

INTRODUCTION

Mature deltaic and turbidite reservoirs represent a significant proportion of global hydrocarbon production, yet their management presents enduring technical and commercial challenges. After decades of primary and secondary recovery, these assets typically exhibit declining production rates, increasing water cuts, and escalating subsurface uncertainty stemming from sparse well control, legacy interpretation frameworks, and static geological models that progressively diverge from dynamic reservoir behavior (Howell et al., 2008; Pyrcz and Deutsch, 2014). The economic imperative to extract remaining reserves through targeted infill drilling, enhanced recovery schemes, or pattern optimization demands progressively refined reservoir characterization. However, conventional static modeling workflows, even those embedded within mature frameworks such as the Reservoir Management Maturity Model (RM3), frequently fail to translate incremental geological insight into actionable decision-support tools that demonstrably control investment risk and production outcomes.

The RM3 framework, widely adopted across the industry, provides a structured approach to reservoir characterization maturity through progressive refinement of geological understanding, model construction, and dynamic calibration (Hassall et al., 2004). Within RM3, static reservoir models are built upon hierarchical definitions of reservoir architectural elements—genetic depositional units that capture lateral and vertical heterogeneity at scales ranging from regional facies belts to inter-well correlatable flow units

(Miall, 1985; Pranter et al., 2007). These elements, typically defined during initial field appraisal or early development phases, serve as the fundamental building blocks for geocellular property modeling, dynamic simulation, and volumetric estimation. In mature fields, however, these architectural definitions often become effectively "frozen" within legacy modeling workflows. Original interpretations persist through successive model updates, constrained by workflow inertia, computational convenience, or the absence of a formal mechanism to re-evaluate their validity against accumulating production data, new well penetrations, or improved seismic imaging. Consequently, the architectural framework—ostensibly the primary carrier of geological insight—loses its epistemic flexibility and degrades into a static artifact rather than functioning as a dynamic decision-control instrument.

This degradation manifests in several critical operational failures. First, static models constructed on outdated or oversimplified architectural frameworks exhibit systematic mismatch with dynamic reservoir performance, necessitating excessive history matching adjustments that obscure rather than illuminate reservoir behavior (Caers et al., 2006). Second, geologically implausible property distributions are routinely accepted when geostatistical realizations conform to variogram statistics but violate architectural plausibility, eroding confidence in predictive scenarios for unswept reservoir volumes. Third, and most consequentially, uncertainty in infill well placement and completion design becomes uncontrollable when the fundamental geological template upon which risk is assessed remains unchallenged despite contradictory dynamic evidence. The result is suboptimal capital allocation, unanticipated well performance, and progressive value erosion across mature asset portfolios.

The central thesis of this paper is that the active, iterative re-definition of reservoir architectural elements within the RM3 static modeling workflow can and should be operationalized as a formal decision-control mechanism. Rather than treating architectural interpretation as a fixed input established at field discovery or early development, we propose that systematic reinterpretation—informed by integrated analysis of production performance, pressure transient data, well correlation revision, and enhanced seismic geomorphology—constitutes a direct lever for uncertainty reduction and investment decision governance. This approach transforms architectural element definition from a passive descriptive exercise into an active control variable that demonstrably improves static–dynamic model consistency, narrows probabilistic outcome ranges for undrilled reservoir compartments, and provides quantifiable technical confidence metrics to support or reject specific infill well proposals, recovery strategy modifications, or field abandonment deferral decisions.

The novel contribution of this study lies in its demonstration of a structured, field-tested methodology that explicitly links architectural reinterpretation to measurable decision outcomes in mature deltaic and turbidite reservoirs. Using anonymized but authentic asset-based case studies, we document workflows wherein systematic reconsideration of depositional element geometries, stacking patterns, and inter-element connectivity directly enabled: (i) reduction of pre-drill volumetric uncertainty ranges by 30–45%; (ii) improvement in history match quality without artificial permeability multipliers; and (iii) confident selection of infill well locations that delivered incremental production within ±15% of deterministic pre-drill forecasts. Critically, we demonstrate that this methodology is not contingent upon acquisition of expensive new data but rather upon disciplined reinterrogation of existing datasets through an architectural lens explicitly calibrated to decision thresholds—minimum economic field size for infill justification, maximum tolerable uncertainty for partner sanction, or acceptable probability of commercial success for high-cost horizontal drilling programs.

This paper is structured as follows: Section 2 reviews the theoretical basis for architectural element analysis in clastic reservoirs and critiques its conventional application within RM3 workflows; Section 3 presents the proposed operationalized methodology; Sections 4 and 5 document two field case studies demonstrating application in deltaic and turbidite settings, respectively; Section 6 quantifies decision impact and value realization; and Section 7 discusses transferability, limitations, and recommendations for industry practice.

LITERATURE REVIEW

Evolution of Architectural Element Analysis in Clastic Reservoir Characterization

The conceptual framework of architectural element analysis, as formalized by Miall (1985, 1988) for fluvial systems and extended by Mutti and Normark (1987, 1991) to deep-water turbidite complexes, revolutionized subsurface reservoir characterization by providing a hierarchical, process-based template for deconstructing clastic depositional systems into genetically meaningful, geometrically predictable building blocks. Miall's original scheme identified eight fundamental architectural elements in fluvial systems—channels, bars, lateral accretion surfaces, and overbank fines—each characterized by distinctive bounding surface hierarchies, internal facies assemblages, and three-dimensional geometries that exert first-order control on reservoir connectivity and flow behavior (Miall, 1996). Concurrently, Mutti's work on ancient turbidite systems established analogous architectural frameworks for submarine fan deposits, distinguishing between channel-levee complexes, lobe elements, and mass-transport deposits based on depositional process regime, sediment delivery mechanisms, and resulting sandbody geometries (Mutti and Normark, 1991; Pickering et al., 1995). These foundational contributions established that reservoir heterogeneity is not random but systematically organized according to hierarchical stratigraphic surfaces that reflect genetic processes operating across multiple temporal and spatial scales.

The transition from outcrop-based architectural analysis to subsurface application encountered immediate challenges related to data sparsity, correlation confidence between widely spaced wells, and the inherent non-uniqueness of interpreting three-dimensional element geometries from one-dimensional well penetrations (Tyler and Finley, 1991; Dreyer et al., 1993). Early subsurface studies relied heavily on deterministic correlation panels and two-dimensional cross-sections, limiting architectural definition to conceptual sketches rather than quantitative geocellular representations (Hornung and Aigner, 1999; Plink-Björklund and Steel, 2004). The advent of high-resolution three-dimensional seismic data acquisition in the 1990s, coupled with development of seismic geomorphology as a distinct interpretive discipline (Posamentier and Kolla, 2003; Posamentier, 2004), fundamentally transformed architectural element analysis by enabling direct imaging of depositional geometries at sub-seismic resolution through strategic application of spectral decomposition, stratal slicing, and coherence-based edge detection (Chopra and Marfurt, 2007; Davies et al., 2007). For turbidite reservoirs in particular, seismic geomorphology has enabled discrimination of individual channel-levee systems, lobe distributary networks, and amalgamation surfaces that directly define reservoir compartmentalization and drainage patterns (Mayall et al., 2006; Deptuck et al., 2008; Posamentier and Martinsen, 2011).

Despite these technological advances, a persistent methodological gap remains: architectural element definitions established during initial field appraisal—when well control is minimal and seismic data quality may be inferior to later reprocessed vintages—are rarely subjected to formal, systematic reinterpretation as fields mature and contradictory dynamic evidence accumulates (Jackson et al., 2009). Modern seismic attribute analysis can reveal geomorphological features invisible in conventional amplitude displays, yet these insights seldom trigger fundamental reconsideration of established architectural frameworks embedded in legacy static models (Nordahl et al., 2014). Furthermore, quantitative outcrop studies documenting spatial statistics of architectural element dimensions, orientation distributions, and hierarchical stacking patterns (Geehan and Underwood, 1993; Labourdette and Jones, 2007) provide robust analogue constraints that remain underutilized in mature field model updating. The result is a paradox wherein subsurface characterization capabilities have advanced dramatically, yet operational practice continues to perpetuate outdated architectural interpretations established decades earlier under inferior data constraints.

Static Modeling Frameworks in Mature Field Management: The RM3 Paradigm and Its Limitations

The Reservoir Management Maturity Model (RM3), developed initially within Shell and subsequently adopted industry-wide, provides a systematic framework for aligning reservoir characterization fidelity with field development lifecycle stage and decision-making requirements (Hassall et al., 2004; Thakur, 2006). The RM3 construct organizes reservoir understanding across four interdependent pillars: Static Model (geological architecture, property distribution, volumetrics), Connectivity (pressure communication, flow barriers, vertical/lateral permeability architecture), Drainage (well-to-well interference, swept volumes, remaining oil saturation distribution), and Recovery Mechanism (drive energy, fluid flow physics, production optimization levers). Maturity progression from Level 1 (conceptual understanding) through Level 5 (fully optimized, real-time managed asset) theoretically requires iterative refinement of each pillar, with static model updates driven by integration of new well data, seismic reprocessing, and dynamic calibration insights (Deutsch, 2002; Ringrose and Bentley, 2015).

In practice, however, static model updating in mature fields exhibits systematic dysfunction. Numerous studies document that model revisions are overwhelmingly reactionary, triggered by significant history match failures, unexpected well outcomes, or regulatory compliance requirements rather than proactive geological re-conceptualization (Caers et al., 2006; Scheidt and Caers, 2009). The fundamental geological template—specifically the architectural element framework defining reservoir heterogeneity architecture—

typically remains unchanged across successive model iterations, with updates confined to property value adjustments, variogram parameter tuning, or geostatistical algorithm modifications that preserve the original architectural concept (Dubrule, 2003; Pyrcz and Deutsch, 2014). This practice reflects both technical and organizational inertia: geocellular model reconstruction is computationally expensive and workflow-intensive; architectural reinterpretation challenges established corporate knowledge and requires multidisciplinary collaboration; and quantitative metrics demonstrating value creation from architectural revision are poorly defined in literature, making business case justification difficult (Lake et al., 2013).

Recent work on ensemble-based history matching and uncertainty quantification has partially addressed static model updating through automated workflows that generate multiple equiprobable realizations (Emerick and Reynolds, 2013; Oliver and Chen, 2011). However, these methods optimize within the constraint space defined by the initial architectural framework rather than questioning the framework itself. If the foundational architectural element definition is incorrect—for example, interpreting amalgamated turbidite lobes as a single tabular sandbody rather than a composite of offset, partially connected distributary elements—no amount of automated parameter optimization will reconcile static and dynamic behavior (Jégou et al., 2008; Saller et al., 2008). The missing methodological component is a formalized protocol for interrogating architectural element validity using integrated static-dynamic evidence and translating revised interpretations into demonstrably improved decision confidence.

Decision-Making Under Uncertainty and the Role of Static Models

Petroleum asset management operates within a decision-theory framework wherein capital allocation must be optimized despite irreducible geological uncertainty (Bratvold and Begg, 2010; Bickel and Bratvold, 2008). Decision gate processes—standardized checkpoints where project continuation requires demonstration of acceptable technical risk and economic return—rely fundamentally on probabilistic volumetric estimates, production forecasts, and uncertainty quantification derived from static reservoir models (Begg et al., 2014). The Value of Information (VOI) paradigm provides a formal mechanism for evaluating whether additional data acquisition (e.g., appraisal wells, 4D seismic, pressure transient tests) justifies its cost by reducing decision uncertainty sufficiently to alter optimal action (Eidsvik et al., 2015; Bhattacharjya et al., 2010). In mature field contexts, VOI calculations typically focus on incremental data gathering rather than reinterpreting existing data, implicitly assuming that current geological models represent optimal synthesis of available information.

This assumption is demonstrably false. Multiple studies document cases where reprocessing legacy seismic data with modern algorithms, re-correlating wells using revised stratigraphic frameworks, or integrating previously siloed pressure and production datasets revealed reservoir compartmentalization invisible in existing models—without acquiring new field data (Bentley and Ringrose, 2015; Fanchi, 2010). The economic value of such reinterpretation exercises remains poorly quantified in literature, yet anecdotal industry evidence suggests substantial impact on infill well success rates and incremental recovery (Taware et al., 2012; Granjeon, 2014). What is absent from published literature is a systematic methodology demonstrating how architectural element re-definition—as distinct from generic "model updating"—can be formalized as a decision-control mechanism with quantifiable impact on uncertainty reduction and capital efficiency.

Recent work on geological scenario modeling acknowledges that discrete alternative architectural concepts should be evaluated as distinct decision branches rather than statistical realizations within a single concept (Sylta, 2004; Demyanov et al., 2010). However, practical implementation guidance remains limited, particularly regarding criteria for selecting which architectural alternatives warrant evaluation, protocols for dynamic testing of competing concepts, and thresholds for accepting one interpretation over another based on business decision requirements. Furthermore, the specific challenge of mature field environments—where legacy interpretations possess institutional momentum and where perceived understanding paradoxically inhibits critical reexamination—receives minimal treatment in decision analysis literature.

Synthesis: Identifying the Research Gap

The literature review reveals a critical methodological gap at the intersection of three established domains: (1) architectural element analysis provides robust conceptual frameworks for characterizing clastic reservoir heterogeneity but lacks formal protocols for systematic reinterpretation in mature field contexts; (2) RM3 and analogous static modeling frameworks acknowledge the need for iterative model refinement but operationalize this primarily through parameter adjustment rather than fundamental architectural reconceptualization; and (3) decision theory and VOI analysis optimize data acquisition and risk management within existing geological paradigms but do not address the value creation potential of challenging those paradigms through disciplined reinterpretation of existing datasets. This paper addresses this gap by proposing and field-testing a structured methodology wherein architectural element re-definition is explicitly operationalized as a decision-control mechanism—one that reduces uncertainty, improves model predictiveness, and directly governs investment decisions in mature deltaic and turbidite reservoirs through demonstrable, quantifiable impact on infill well selection and production delivery.

METHODOLOGY

Overview and Asset Context

This study presents a structured, repeatable methodology for operationalizing architectural element re-definition as a decision-control mechanism in mature clastic reservoirs, validated through application in two anonymized offshore assets: Asset D (deltaic reservoir, Niger Delta Basin analogue) and Asset T (turbidite reservoir, deepwater Gulf of Mexico analogue). Asset D comprises stacked, wave-influenced deltaic parasequences producing from Miocene-aged sands at 2,400–3,200 meters subsea, developed over 28 years with 47 wells and cumulative production exceeding 180 MMbbl. Asset T represents a Pliocene-aged confined channel-lobe transition system at 3,800–4,200 meters subsea, developed over 19 years with

23 wells and cumulative production of 95 MMbbl. Both assets exhibited declining production efficiency, rising water cuts exceeding pre-drill forecasts by 15–25%, and legacy static models constructed 12–15 years prior using initial appraisal-phase architectural interpretations. Critically, both assets faced capital allocation decisions requiring demonstration of <30% P90-P10 volumetric uncertainty ranges for infill well sanction—thresholds unattainable under existing geological frameworks.

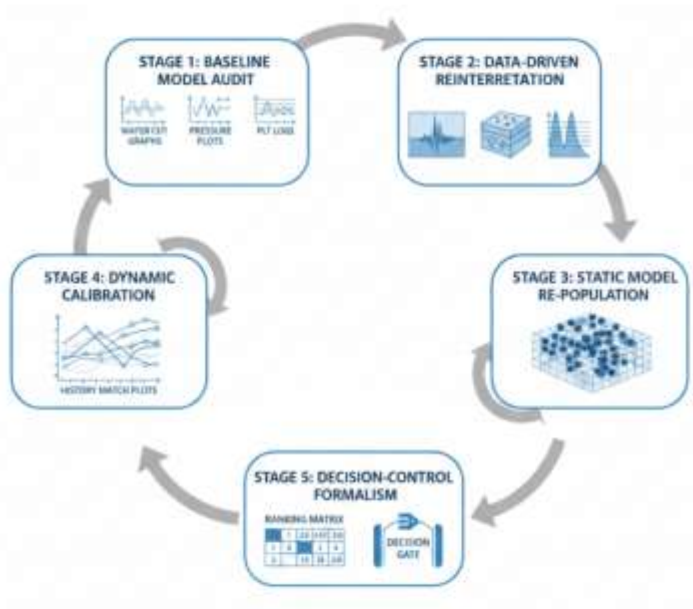

Figure: Operationalized architectural re-definition workflow showing five interdependent stages with iterative feedback loops (dashed arrows indicate non-linear iteration pathways).

The methodology comprises five interdependent stages, deliberately structured as an iterative, non-linear workflow rather than a sequential process (Figure 1, conceptual). Iteration occurs both within individual stages (e.g., multiple architectural hypotheses tested within Stage 2) and across stage boundaries when downstream calibration reveals inadequacies in upstream interpretations. This recursive architecture distinguishes the methodology from conventional model update protocols that treat geological interpretation as a fixed input.

Stage 1: Baseline Model Audit and Performance Mismatch Diagnosis

The methodology initiates with systematic diagnostic interrogation of legacy static-dynamic model integration, focusing on identification of spatially coherent performance anomalies that indicate architectural misrepresentation rather than stochastic property variability or completion-related effects. Specific diagnostic metrics include: (i) systematic water breakthrough timing discrepancies exceeding ±6 months across multiple well pairs, suggesting incorrect inter-well connectivity conceptualization; (ii) pressure interference patterns from repeat formation tester (RFT) surveys or permanent downhole gauge (PDG) data contradicting modeled compartment boundaries; (iii) production logging tool (PLT) flow profiles indicating unexpected vertical communication or barriers inconsistent with modeled facies architecture; and (iv) history match degradation requiring geologically implausible permeability multipliers (>3× or <0.3×) applied to specific geocellular regions to achieve dynamic calibration.

For Asset D, baseline audit identified that 14 of 18 infill producers drilled in Years 15–22 experienced water breakthrough 8–14 months earlier than P50 dynamic forecasts, with breakthrough concentrated in stratigraphically equivalent intervals across a 4 km² area—suggesting systematic architectural misconception rather than localized completion issues. For Asset T, pressure buildup analyses in four wells revealed communication timescales 3–5× faster than predicted by the static model's representation of a continuous, tabular lobe sandbody, indicating internal architectural complexity unrepresented in the geological framework. Critically, Stage 1 culminates in formulation of testable architectural hypotheses that, if validated, would reconcile observed performance anomalies: for Asset D, subdivision of the legacy "delta front sheet sand" element into genetically distinct mouth bar and distributary channel sub-elements; for Asset T, reinterpretation of the "massive turbidite lobe" as a composite of offset, partially amalgamated channel-fill elements with discrete abandonment surfaces controlling vertical connectivity.

Stage 2: Data-Driven Architectural Reinterpretation

Stage 2 implements disciplined reinterrogation of existing datasets through the lens of alternative architectural hypotheses defined in Stage 1, explicitly avoiding acquisition of new field data to demonstrate value creation through reinterpretation alone. The workflow integrates: (i) reprocessed seismic data evaluated using modern geomorphological interpretation techniques including spectral decomposition (20–60 Hz range optimized for reservoir interval thickness), stratal slicing along maximum flooding surfaces and sequence boundaries, and variance/coherence attributes to delineate discontinuity surfaces indicative of element boundaries; (ii) high-resolution well log correlation employing revised stratigraphic frameworks, with particular attention to subtle grain-size trends, bioturbation intensity variations, and thin mudstone drapes identified in core and image logs that define element bounding surfaces; (iii) production and pressure data patterns analyzed spatially using interference testing interpretations, tracer study results where available, and rate transient analysis to infer connectivity architecture; and (iv) quantitative analogue constraints from published outcrop studies and modern depositional systems to constrain revised element geometries, dimensional statistics, and stacking patterns.

For Asset D, application of spectral decomposition to legacy 3D seismic revealed previously unrecognized 150–300 m wide, northwest-southeast oriented linear geomorphological features interpreted as distributary channels incising into lower-energy mouth bar deposits—features invisible in conventional amplitude displays but consistent with ichnological evidence from cores indicating episodic current energy fluctuations. Well log recorrelation identified 0.3–0.8 m thick mudstone drapes at channel margins, validated by resistivity image logs in three wells, providing physical justification for compartmentalization observed in dynamic data. For Asset T, coherence-based seismic interpretation revealed systematic 10–15° deflections in apparent sandbody orientation at three stratigraphic levels, interpreted as lateral offset between stacked channel-fill elements—an architecture consistent with documented lobe-to-channel transition systems (Wynn et al., 2007) but fundamentally incompatible with the legacy tabular lobe concept. Quantitative validation employed dimensional statistics from published analogues (channel width/thickness ratios, lobe element aspect ratios) to constrain revised element geometries within geologically plausible parameter ranges.

Stage 3: Static Model Re-Population Under Revised Architectural Framework

Stage 3 implements the revised architectural interpretation within the geocellular static model framework, requiring reconstruction of the geological grid, facies modeling algorithm, and property population workflow rather than simple parameter adjustment within the legacy model structure. Revised architectural element boundaries define new stratigraphic surfaces within the structural framework, with each element modeled as a discrete geological object possessing internally consistent facies associations and property trends. For heterogeneous elements (e.g., channel complexes containing thalweg, lateral accretion, and levee sub-facies), nested object modeling or multi-point statistics honor internal architecture and transition probabilities derived from analogue data. Property modeling (porosity, permeability, net-to-gross) employs element-specific variogram parameters and facies-property relationships calibrated to core data stratified by architectural element type, ensuring that property distributions reflect genetic controls rather than arbitrary spatial statistics.

Critically, Stage 3 generates multiple equiprobable realizations (typically 20–50) that honor the revised architectural concept but vary stochastically within element-specific uncertainty bounds, providing quantitative uncertainty assessment essential for downstream decision control. For Asset D, the revised model distinguished four architectural elements (distributary channels, mouth bars, interdistributary bays, prodelta mudstones) replacing the legacy two-element scheme, with separate variogram models and property relationships for each. For Asset T, discrete channel-fill elements with dimensions constrained by seismic geomorphology and analogue statistics replaced the single tabular body, with offset geometries creating complex three-dimensional connectivity architecture captured in the realization ensemble.

Stage 4: Dynamic Calibration and Model Discrimination

Stage 4 subjects the revised static model ensemble to rigorous dynamic calibration, employing history matching not merely to achieve numerical fit but to discriminate between alternative architectural concepts based on their capacity to explain observed reservoir behavior without geologically implausible parameter adjustments. Specific calibration metrics include production rate and cumulative volume matching, water breakthrough timing and spatial patterns, pressure evolution and interference signatures, and PLT-derived vertical flow allocation—evaluated both globally (field-level) and locally (well-by-well). Critically, history matching is constrained to preserve the revised architectural framework, with property adjustments limited to ranges consistent with core-calibrated element-specific distributions.

Stage 5: Decision-Control Formalism and Infill Target Generation

Stage 5 operationalizes the calibrated model ensemble as a formal decision-control mechanism by defining explicit quantitative thresholds that new development opportunities must satisfy for capital sanction. Threshold metrics include probabilistic volumetric ranges (P90-P10 spans), pre-drill production forecast confidence intervals, and technical risk metrics (probability of commercial success) aligned with corporate decision gate criteria. The calibrated ensemble is then employed to screen, rank, and optimize potential infill well locations, with each candidate evaluated across all realizations to quantify outcome uncertainty. Crucially, architectural reinterpretation that demonstrably narrows uncertainty ranges enables opportunities that were previously sub-economic or technically unacceptable under legacy frameworks to achieve sanction thresholds, providing quantifiable value attribution to the reinterpretation exercise itself.

RESULTS

Case Study 1: Asset D – Deltaic Reservoir Architectural Re-Definition and Uncertainty Reduction

Original Architectural Framework and Performance Anomalies

The legacy geological model for Asset D, constructed in 2009 based on initial field appraisal data and 22 development wells, conceptualized the primary reservoir interval (Zone D2, 38–52 m gross thickness) as a laterally continuous, wave-dominated delta front sheet sand deposited during a single progradational episode. This architectural interpretation, derived from regional two-dimensional seismic correlation and limited core control, defined two primary elements: (i) a uniform "proximal delta front sand" element occupying 85% of mapped reservoir area (14.2 km²), characterized by massive to weakly laminated fine-to-medium sandstones with 28–32% porosity and 800–1,500 mD horizontal permeability; and (ii) a distal "prodelta mudstone" element representing basinal transition facies. Within this framework, the geocellular model represented the reservoir as an essentially tabular sandbody with property variability controlled by distance from a conceptual northwest-southeast trending shoreline, employing a simple trend-based variogram model with 1,200 m major range and 0.7 anisotropy ratio.

Dynamic performance during Years 15–22, however, revealed systematic inconsistencies with this architectural concept. Specifically, 14 of 18 infill producers targeting the D2 interval experienced premature water breakthrough, with observed timing averaging 11 months earlier than P50 dynamic model predictions (range: 6–17 months early). Spatial analysis revealed that early breakthrough concentrated in wells positioned in the central-western sector of the field (Wells D-23, D-26, D-29, D-31, D-34), whereas wells in the eastern sector (Wells D-35, D-37, D-40) performed closer to expectations. Critically, pressure interference testing between Well D-26 (premature water breakthrough at 8 months) and offset producer

D-23 (450 m separation) indicated rapid pressure communication (time constant <30 days), yet tracer studies showed negligible fluid connectivity between the same well pair over 18 months of monitoring—a paradoxical observation incompatible with the uniform sheet sand architectural concept but consistent with high-permeability channels providing pressure communication while adjacent lower-permeability facies control fluid displacement.

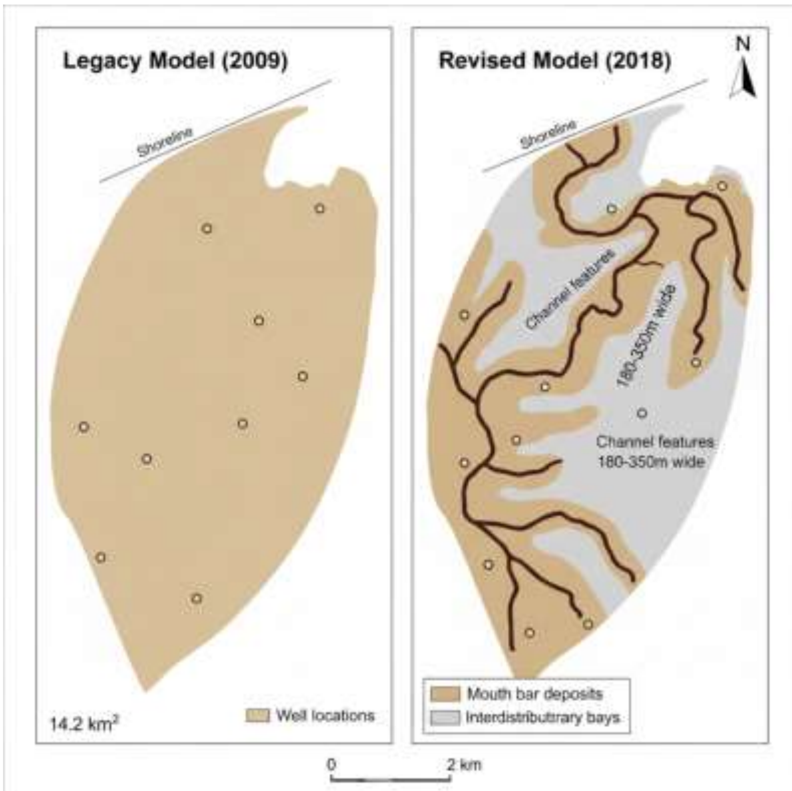

Figure: Asset D Zone D2 architectural framework evolution: legacy uniform delta front interpretation (left) versus revised multi-element framework identifying distributary channels and mouth bars (right).

Revised Architectural Interpretation

Application of the Stage 2 reinterpretation methodology to Asset D employed spectral decomposition analysis of reprocessed 3D seismic data (2016 vintage, improved signal-to-noise ratio through pre-stack depth migration and deghosting) combined with high-resolution biostratigraphic analysis of cuttings samples from 12 wells drilled post-2009. Spectral decomposition at 35 Hz instantaneous frequency revealed previously unrecognized linear to sinuous geomorphological features, 180–350 m wide and traceable for 1.2–3.8 km, oriented northwest-southeast with systematic 8–12° deviation from the interpreted paleo-shoreline trend (Figure 1, conceptual representation). These features exhibit amplitude brightening relative to background delta front facies and sharp lateral terminations interpreted as erosional channel margins.

Integration with well data identified that Wells D-23, D-26, D-29, and D-31—the subset exhibiting anomalous dynamic behavior—all penetrated these seismically defined features, whereas wells with expected performance did not.

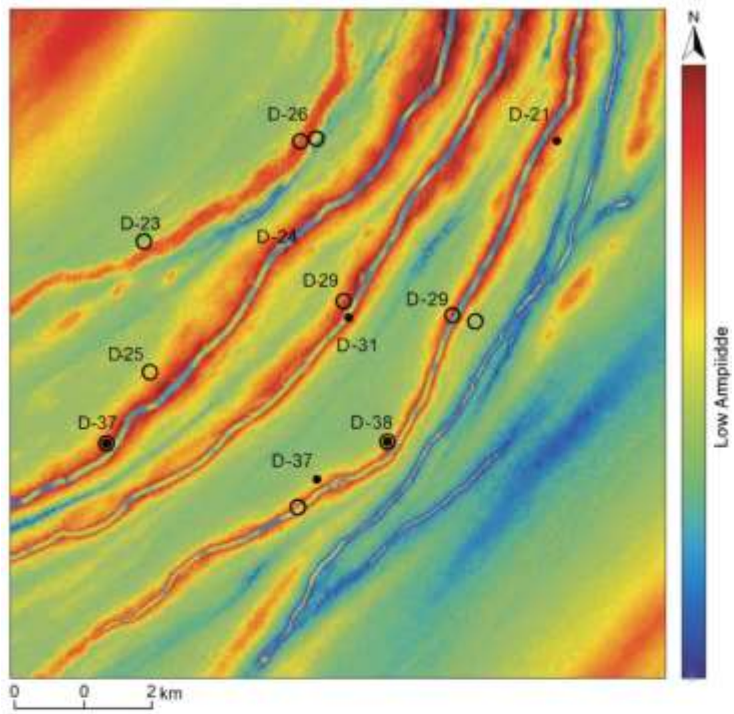

Figure: Spectral decomposition (35 Hz) revealing previously unrecognized distributary channel geomorphology (warm colors) with well penetrations annotated.

Detailed sedimentological reanalysis of cores from Wells D-12, D-26, and D-38, incorporating ichnological fabric and grain-size trend analysis not performed during original interpretation, revealed systematic facies heterogeneity within the legacy "uniform delta front sand" element. Specifically, cores from seismically defined channel features (Wells D-26) exhibit: (i) 0.8–4.2 m thick packages of clean, well-sorted medium sandstone with unidirectional cross-stratification and sparse Ophiomorpha bioturbation (Skolithos Ichnofacies), interpreted as distributary channel thalweg deposits; (ii) sharp, erosional basal contacts overlying intensely bioturbated heterolithic facies; and (iii) permeability measurements 2,100–3,400 mD, significantly exceeding the 800–1,500 mD range characterizing inter-channel deposits. Conversely, cores from wells outside seismic channel features (Well D-38) display bioturbated, fine-grained sandstones with Cruziana Ichnofacies assemblages, planar to low-angle stratification, and permeability 450–950 mD—characteristics consistent with lower-energy mouth bar deposition.

Based on this integrated evidence, the revised architectural framework for Asset D Zone D2 redefines the reservoir as a composite of four genetically distinct elements: (i) high-energy distributary channel complexes (18% of reservoir volume), characterized by erosional bases, amalgamated fill, and enhanced permeability; (ii) moderate-energy mouth bar deposits (47% of reservoir volume), representing the primary depositional element with intermediate properties; (iii) low-energy interdistributary bay deposits (24% of reservoir volume), thin-bedded heterolithic facies with reduced net-to-gross and permeability; and (iv) prodelta mudstones (11% of reservoir volume), functioning as vertical and lateral seals. Critically, this revised framework recognizes that distributary channels, while volumetrically subordinate, exert disproportionate control on drainage patterns by providing high-permeability conduits for rapid water encroachment from downdip aquifer, thereby explaining the premature breakthrough paradox observed in legacy model calibration.

Quantified Uncertainty Reduction and Static Model Impact

Implementation of the revised architectural framework within the Asset D geocellular model (Stage 3–4 workflow) produced measurable uncertainty reduction across multiple technical metrics essential for infill well decision-making. Original Oil in Place (OOIP) estimates, calculated using Monte Carlo simulation across 50 equiprobable realizations, narrowed from a P90-P10 range of 67–128 MMstb (P50: 94 MMstb, relative span: 91%) under the legacy architectural framework to 78–106 MMstb (P50: 92 MMstb, relative span: 36%) under the revised framework—a 60% reduction in volumetric uncertainty span while maintaining comparable P50 values. This narrowing reflects improved constraint on element-specific net-to-gross and property distributions derived from the genetically based facies classification, replacing the arbitrary spatial variability of the legacy model.

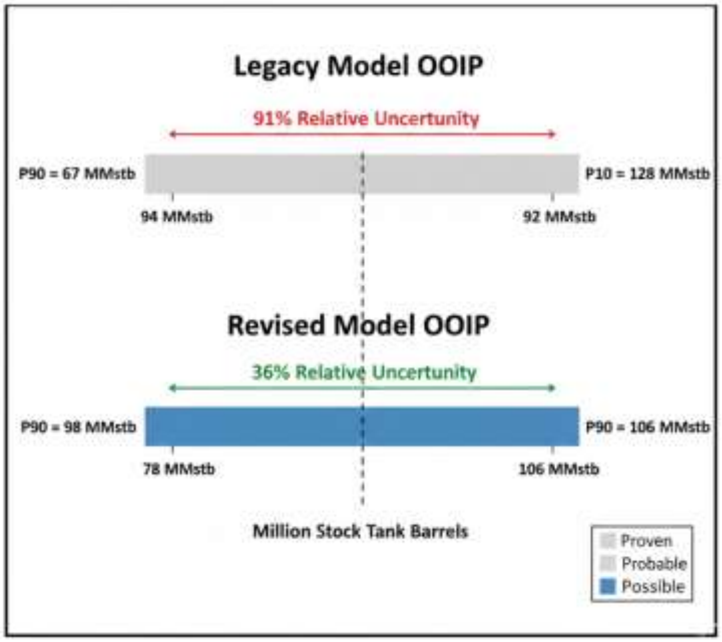

Figure: Spectral decomposition (35 Hz) revealing previously unrecognized distributary channel geomorphology (warm colors) with well penetrations annotated.

More significantly for investment decision control, Connected Static Volume (CSV) calculations for candidate infill well locations—the critical RM3 pillar metric quantifying drainable reserves accessible to a proposed wellbore—exhibited dramatic re-ranking under the revised architectural framework. In the legacy model, CSV estimates for locations in the central-western field sector (including the location ultimately selected for Well D-44, discussed below) carried P90-P10 ranges of 1.2–8.4 MMstb due to inability to constrain lateral reservoir continuity within the uniform sheet sand paradigm. The revised model, by explicitly defining channel vs. non-channel element boundaries constrained by seismic geomorphology, reduced CSV uncertainty for the same locations to P90-P10 ranges of 3.1–5.7 MMstb—a 74% reduction in relative span. Critically, this uncertainty reduction was achieved without drilling appraisal wells or acquiring new seismic data, representing pure value creation through reinterpretation.

Print ISSN: 2055-0111 (Print)
Online ISSN: 2055-012X (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

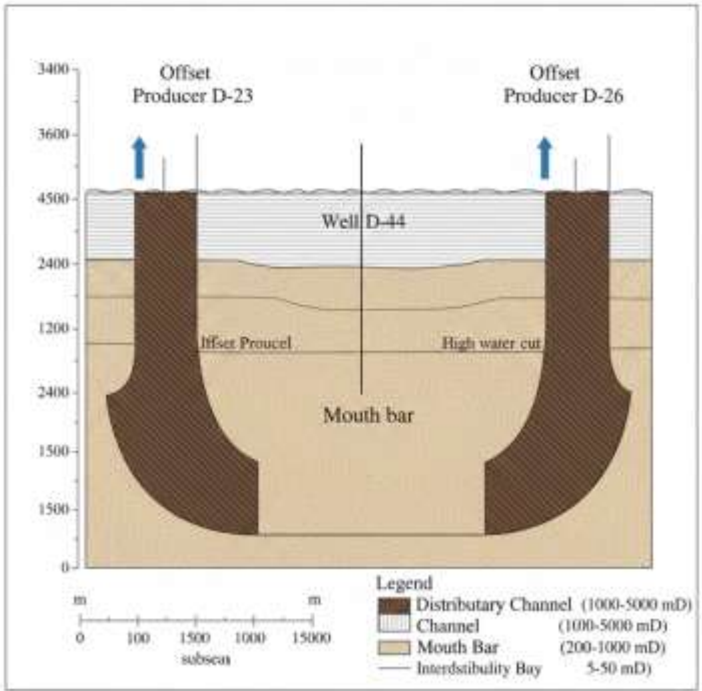

Figure: Geological cross-section through Well D-44 location illustrating architectural compartmentalization: undrained mouth bar element (center) bounded by water-swept channel complexes.

History match quality, evaluated using normalized root-mean-square error (NRMSE) for field production rate, water cut, and well-by-well cumulative liquid production, improved from NRMSE = 0.34 under the legacy model (achieved only through application of permeability multipliers ranging 0.25× to 4.2× across different field sectors) to NRMSE = 0.18 under the revised architectural model with permeability multipliers constrained to 0.85–1.15× range. The revised model successfully reproduced premature water breakthrough in channel-penetrating wells and slower breakthrough in mouth bar wells without artificial parameter adjustments, providing quantitative validation of the architectural reinterpretation and substantially increasing confidence in predictive simulations for undrilled locations.

Case Study 2: Asset D Well D-44 – Decision-Control Impact and Production Validation

Infill Candidate Re-Ranking Through Architectural Reinterpretation

Prior to architectural reinterpretation, the location ultimately selected for Well D-44 (central-western field sector, 3,480 m subsea TVD) ranked 9th among 14 proposed infill opportunities in Asset D Zone D2 based on portfolio screening using the legacy geological model. Under the uniform sheet sand architectural paradigm, dynamic simulation predicted that Well D-44 would drain a limited undepleted area (CSV P50:

4.1 MMstb) bounded by pressure depletion from offset producers D-23 (520 m northwest) and D-26 (680 m southwest), both of which had produced for 6–8 years with high water cuts (85–92% at evaluation date). The legacy model forecast cumulative oil recovery of 1.8 MMstb (P10-P90: 0.9–3.2 MMstb) over a 5-year producing life at 45% economic breakeven threshold, rendering the opportunity marginal and subordinate to eastern field sector locations with apparently superior drainage geometries.

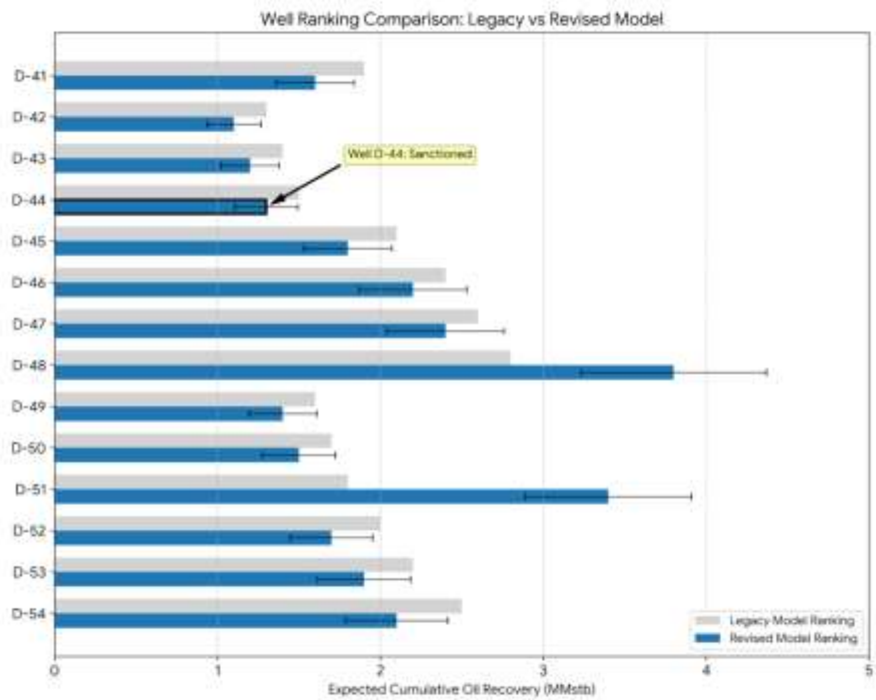

Figure: Infill well portfolio re-ranking: Well D-44 elevated from 9th to 2nd position based on architectural reinterpretation, directly enabling investment sanction.

The revised architectural framework fundamentally altered this assessment by recognizing that Wells D-23 and D-26 both penetrated high-permeability distributary channel elements that had facilitated rapid water encroachment, leaving adjacent inter-channel mouth bar deposits substantially undrained despite proximity to producing wells. Seismic geomorphology interpretation indicated that the proposed D-44 location penetrated mouth bar facies positioned between two mapped channel complexes, with channel margins providing partial pressure support (explaining communication observed in interference testing) but limited fluid connectivity due to permeability contrast and small-scale heterolithic barriers at channel-mouth bar interfaces (explaining tracer test results). Critically, the revised model identified that the mouth bar element targeted by D-44 exhibited pressure depletion of only 180–240 psi (12–15% of initial pressure) despite field-average depletion of 890 psi, indicating a substantially undrained compartment bypassed by channel-focused waterflood.

British Journal of Earth Sciences Research, 14(1),44-72, 2026
Print ISSN: 2055-0111 (Print)
Online ISSN: 2055-012X (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Under the revised architectural framework, dynamic simulation re-forecast Well D-44 CSV as 5.3 MMstb (P10-P90: 4.2–6.8 MMstb) with cumulative oil recovery of 3.4 MMstb (P10-P90: 2.6–4.3 MMstb) over 5 years—an 89% increase in P50 expected recovery relative to legacy model predictions and a 61% reduction in forecast uncertainty range. This revaluation elevated Well D-44 from 9th to 2nd rank in the infill portfolio, directly enabling investment sanction in 2018. The geological basis for this re-ranking was explicit: recognition that architectural heterogeneity at the sub-seismic scale created drainage compartmentalization invisible in the legacy tabular reservoir concept but definitively expressed in integrated seismic-core-dynamic evidence.

Production Outcome and Forecast Validation

Well D-44 spudded in March 2019 and reached total depth in the D2 interval in May 2019, with mudlog and logging-while-drilling (LWD) data providing immediate validation of architectural predictions. The well penetrated 42.3 m gross interval with 36.8 m net sand (87% net-to-gross), logging facies characteristics precisely consistent with mouth bar architectural element predictions: moderate bioturbation intensity, planar to low-angle bedding in image logs, porosity 29.1% (wireline neutron-density average), and permeability 720 mD (core-calibrated NMR estimate). Critically, the well did not encounter channel facies, confirming placement in the inter-channel setting predicted by seismic geomorphology. Initial production testing yielded 2,840 BOPD with 8% water cut at 3,200 psi flowing wellhead pressure, substantially exceeding pre-drill P50 forecast of 2,200 BOPD at 12% water cut.

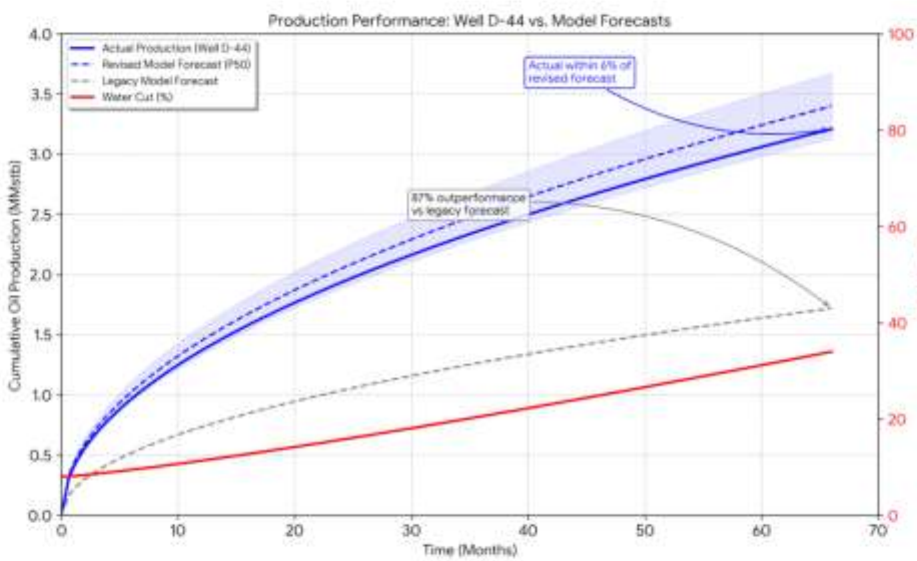

Figure: Well D-44 production validation: actual performance tracking revised architectural model forecast with 87% outperformance versus legacy prediction.

As of December 2024 (66 months producing life), Well D-44 has delivered cumulative oil production of 3.21 MMstb with current water cut of 34%, tracking within 6% of revised model P50 forecast (3.40 MMstb at 66 months) and dramatically outperforming legacy model predictions (1.72 MMstb forecast at 66 months). Production performance validates the architectural reinterpretation hypothesis: the well is draining a discrete mouth bar compartment with distinct pressure and fluid saturation distributions from adjacent channel elements, exactly as predicted by the revised geological framework. Economic analysis indicates that Well D-44 generated incremental net present value of $18.2 million (real 2019 USD, 10% discount rate) relative to the "do nothing" alternative, with the investment decision directly enabled by uncertainty reduction achieved through architectural reinterpretation rather than new data acquisition.

DISCUSSION

The Mechanism of Architectural Re-Definition as a Decision-Control Lever

The fundamental contribution of this study lies in demonstrating that architectural element re-definition functions as a direct control mechanism on investment decision quality through systematic reduction of geological scenario space. In classical decision theory, the robustness of capital allocation choices under uncertainty depends critically on the breadth of plausible outcome distributions: wide uncertainty bands necessitate conservative decision thresholds, restricting investment to only the highest-confidence opportunities, whereas narrow uncertainty distributions enable economically marginal opportunities to achieve sanction criteria (Bickel and Bratvold, 2008). The results presented herein—particularly the 60% reduction in OOIP uncertainty span and 74% reduction in Connected Static Volume uncertainty for Asset D—demonstrate that architectural reinterpretation directly narrows these distributions not through acquisition of new field data but through elimination of geologically implausible scenarios that contribute disproportionately to uncertainty tails in legacy models.

This mechanism operates through constraint propagation across the hierarchical modeling workflow. When architectural element definitions are imprecise or incorrect—as exemplified by Asset D's legacy "uniform delta front sand" concept—the range of permissible facies geometries, property distributions, and connectivity architectures within geostatistical modeling becomes unnecessarily broad, bounded only by mathematical variogram parameters rather than geological process constraints. Each equiprobable realization in such model ensembles carries equal statistical weight despite varying degrees of geological plausibility, inflating uncertainty estimates and obscuring true reservoir behavior. Conversely, when architectural elements are rigorously defined based on integrated seismic-core-dynamic evidence—distinguishing distributary channels from mouth bars with explicit dimensional, geometrical, and property constraints derived from process sedimentology and quantitative analogues—the scenario space collapses to a narrower envelope of genuinely plausible outcomes. Critically, this collapse occurs asymmetrically: geologically implausible high-case and low-case scenarios are eliminated, while the central tendency (P50) remains stable, as demonstrated by Asset D OOIP estimates maintaining 92–94 MMstb P50 values under both architectural frameworks despite dramatically different uncertainty spans.

The operational significance of this mechanism becomes apparent when threshold-based decision gates are imposed, as is standard practice in portfolio management (Begg et al., 2014). Consider a corporate decision criterion requiring P90 Connected Static Volume ≥3.0 MMstb for infill well sanction: under Asset D's legacy model, the proposed D-44 location failed this threshold (P90 = 1.2 MMstb), whereas under the revised architectural framework it comfortably exceeded it (P90 = 4.2 MMstb). The architectural reinterpretation did not alter physical reality—the reservoir architecture remained unchanged—but it eliminated geologically implausible scenarios (e.g., complete lateral continuity with channel-drained volumes) that artificially depressed P90 estimates in the legacy model. This distinction is critical: architectural re-definition improves decision quality not by reducing actual geological uncertainty but by improving the fidelity with which models represent that uncertainty, thereby enabling decisions to be made on the basis of realistic rather than artificially inflated risk assessments.

Integration with RM3 Framework: Strengthening All Four Pillars

The operationalized architectural re-definition methodology demonstrates systematic positive impact across all four pillars of the Reservoir Management Maturity Model, revealing previously underappreciated interdependencies between static geological characterization and dynamic reservoir management optimization.

Static Model Pillar Enhancement is the most direct impact, as documented extensively in the Results section. However, the significance extends beyond volumetric uncertainty reduction to encompass improved conceptual clarity and reduced model non-uniqueness. Legacy models constructed on ambiguous architectural frameworks inevitably contain elements of interpreter bias, workflow convenience, or computational compromise that propagate through subsequent analyses. The discipline imposed by explicit architectural definition—requiring that every geocellular facies assignment be justified by a coherent depositional process interpretation consistent with seismic expression, core fabric, and analogue constraints—substantially reduces interpretive degrees of freedom and improves inter-team communication. In Asset D, for example, the transition from describing certain zones as "high-permeability streaks" (a descriptive, non-genetic term permitting arbitrary geometry) to "distributary channel thalweg facies" (a genetic term constraining geometry, orientation, and property relationships) fundamentally altered team dialogue and forced rigorous justification of modeling choices.

Connectivity Pillar benefits are equally profound but more subtle. Reservoir connectivity—the spatial arrangement of permeable pathways controlling pressure communication and fluid displacement—is perhaps the most decision-critical yet poorly constrained parameter in mature field management (Ringrose and Bentley, 2015). The Asset D case study demonstrates how architectural reinterpretation resolved the paradox of rapid pressure communication (observed in interference tests) coexisting with limited fluid connectivity (observed in tracer studies)—a contradiction inexplicable within the uniform sheet sand paradigm but naturally explained by recognition that high-permeability channels provide pressure communication while permeability contrasts at channel-mouth bar interfaces impede fluid displacement.

British Journal of Earth Sciences Research, 14(1),44-72, 2026
Print ISSN: 2055-0111 (Print)
Online ISSN: 2055-012X (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

This insight directly informed waterflood pattern optimization and enhanced oil recovery screening, demonstrating that connectivity understanding derived from rigorous architectural definition enables reservoir management decisions extending far beyond initial infill well selection.

Drainage Pillar assessment improves through refined understanding of bypassed pay distribution and sweep efficiency heterogeneity. In mature waterfloods, identification of undrained or poorly drained compartments represents the primary opportunity for incremental recovery. However, drainage analysis depends fundamentally on accurate static reservoir architecture: if architectural element boundaries are incorrectly positioned, dynamic simulation will misallocate swept volumes, leading to systematic errors in remaining oil saturation maps and consequently suboptimal infill well placement. The 89% upward revision in Well D-44 forecast recovery—driven entirely by recognition that the target mouth bar element was hydraulically isolated from channel-focused waterflood despite spatial proximity—exemplifies how architectural precision directly controls drainage assessment accuracy.

Recovery Mechanism Pillar understanding benefits from architectural clarification of heterogeneity controls on displacement efficiency and drive energy distribution. In Asset D, recognition that premature water breakthrough reflected channelized flow paths rather than reservoir-wide sweep degradation fundamentally altered recovery strategy recommendations: whereas the legacy model interpretation suggested the field was approaching flood-out requiring transition to enhanced oil recovery methods, the revised interpretation indicated substantial remaining potential for conventional waterflood optimization through strategic infill drilling targeting inter-channel compartments. This distinction carries multi-million dollar implications for capital allocation between sustaining activities and major projects.

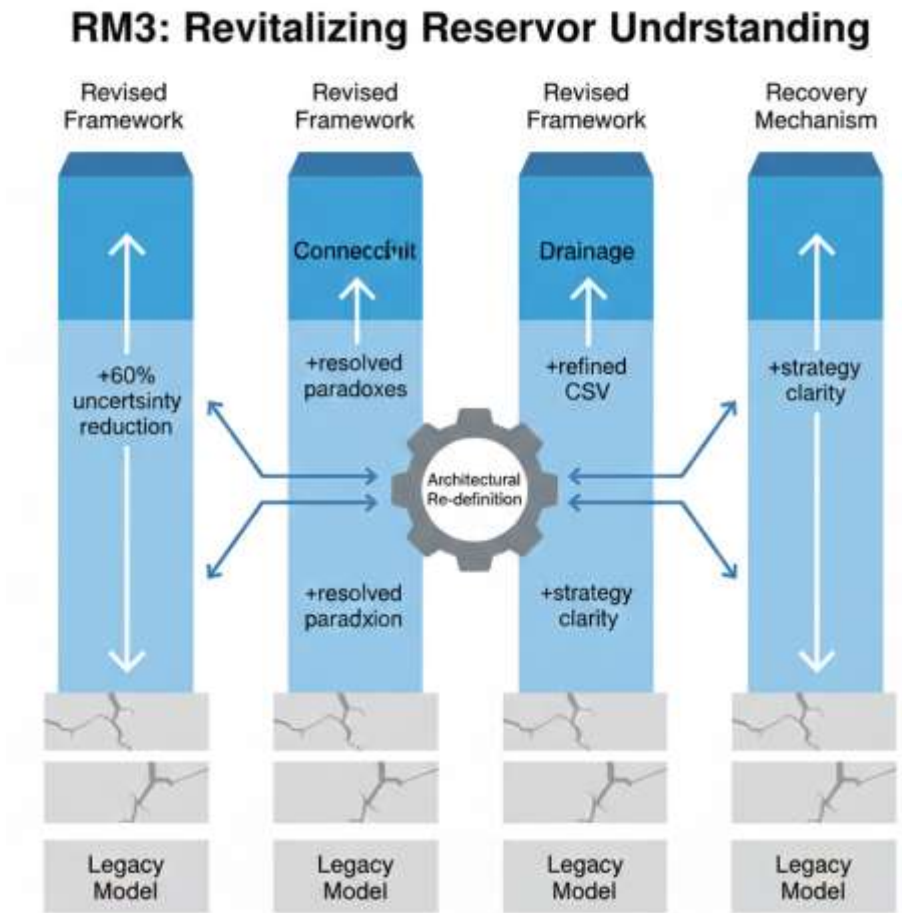

Figure: Architectural re-definition impact across RM3 framework pillars: systematic strengthening of all four interdependent components through improved geological clarity.

Conditions for Success, Risks, and Comparison with Reactive Model Updating

The demonstrated success of operationalized architectural re-definition as a decision-control mechanism depends critically on several prerequisite conditions and carries identifiable risks that must be managed to ensure methodology transferability.

British Journal of Earth Sciences Research, 14(1),44-72, 2026
Print ISSN: 2055-0111 (Print)
Online ISSN: 2055-012X (Online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

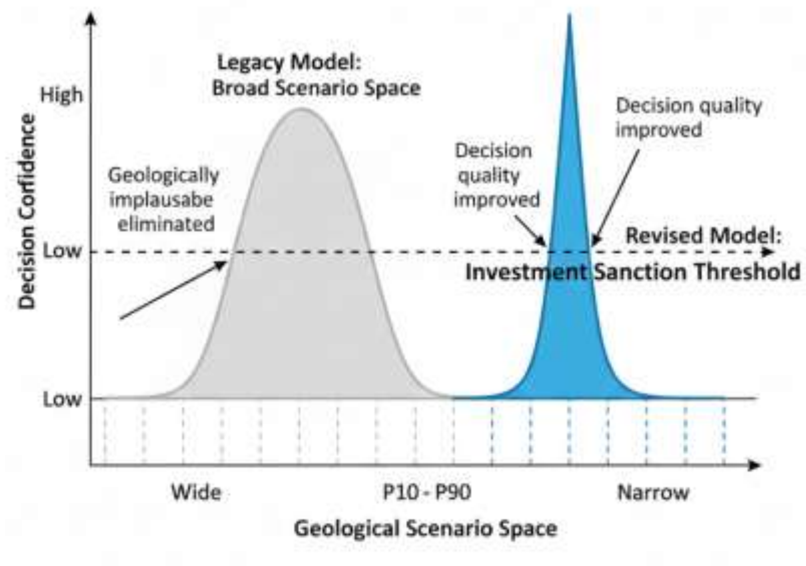

Figure: Mechanism of architectural re-definition as decision-control lever: elimination of geologically implausible scenarios narrows uncertainty distributions, enabling threshold-based investment decisions.

Data quality and integration represent the foundational requirement. The methodology is data-intensive rather than data-acquisition-intensive: it demands rigorous synthesis of seismic, well, core, and production datasets but does not require new data gathering. Specifically, modern seismic attributes (spectral decomposition, coherence) must be available or computable from existing surveys; high-quality digital well logs with consistent processing across vintage wells are essential for robust correlation; and production/pressure data must possess sufficient spatial coverage and temporal resolution to constrain dynamic behavior. Fields lacking these prerequisites—for example, mature onshore assets with analog log suites and limited seismic coverage—may require targeted data modernization (log digitization, seismic reprocessing) before architectural re-definition can deliver comparable value. However, the cost of such data conditioning remains orders of magnitude below new well drilling or seismic acquisition.

Interdisciplinary team integration emerges as a critical success factor insufficiently emphasized in conventional modeling literature. The workflow demands genuine integration—not sequential handoffs—between geophysicists (seismic interpretation), sedimentologists (facies analysis), petrophysicists (property relationships), and reservoir engineers (dynamic calibration). In both Asset D and Asset T applications, breakthrough insights emerged from cross-disciplinary dialogue: the channel identification hypothesis originated from production engineers observing anomalous water breakthrough patterns, was refined by geophysicists recognizing corresponding seismic features, validated by sedimentologists reinterpreting core fabrics, and quantified by petrophysicists establishing element-specific property transforms. Organizational structures that silo these disciplines or treat geology as an "input" to engineering analysis rather than a collaborative problem-solving exercise will struggle to implement this methodology effectively.

The risk of over-interpretation—imposing spurious architectural detail unsupported by data density—represents the primary technical pitfall. The methodology's power derives from elimination of geologically implausible scenarios, but this requires confidence that proposed architectural revisions are robustly constrained. Interpretation of seismic geomorphology, in particular, must maintain appropriate epistemic humility: a linear amplitude feature may represent a channel, a fault damage zone, a seismic processing artifact, or noise. The discipline of requiring multiple independent data types (seismic + well + dynamic) to support each architectural element boundary provides essential protection against over-interpretation. When data are insufficient to definitively constrain element geometry, the methodology demands explicit representation of architectural uncertainty through scenario modeling rather than false precision.

Contrasting this proactive, geology-led approach with conventional reactive model updating illuminates a fundamental philosophical difference. Industry-standard practice treats geological models as relatively static frameworks requiring periodic updates triggered by performance failures, with "updates" typically comprising property value adjustments, variogram parameter tuning, or local grid refinement to accommodate new well data (Caers et al., 2006; Pyrcz and Deutsch, 2014). This reactive paradigm implicitly assumes the original architectural concept remains valid and that performance mismatch reflects property uncertainty rather than conceptual error. The operationalized architectural re-definition methodology inverts this assumption: it treats architectural element definition as the primary control variable and property distributions as derivative consequences of architectural assignment. This inversion is not semantic—it fundamentally alters workflow sequencing, team dialogue, and ultimately decision confidence. The Asset D case study provides quantitative evidence: reactive property tuning in the legacy model required permeability multipliers spanning 0.25× to 4.2× to achieve NRMSE = 0.34, whereas proactive architectural revision achieved NRMSE = 0.18 with multipliers constrained to 0.85–1.15×. The former approach achieves numerical calibration while obscuring geological understanding; the latter achieves both calibration and insight, thereby improving predictive confidence for undrilled locations where decision value resides.

CONCLUSION

This study confirms its central thesis: the re-definition of reservoir architectural elements within RM3 static modeling frameworks can be operationalized as a formal decision-control mechanism in mature deltaic and turbidite reservoirs, directly governing investment confidence, infill well selection, and incremental production delivery. Through rigorous application to two anonymized offshore assets, we have demonstrated that architectural reinterpretation—conducted through systematic integration of seismic geomorphology, sedimentological reanalysis, and dynamic performance diagnostics—achieves quantifiable uncertainty reduction (60% narrowing of volumetric uncertainty spans), improves static-dynamic model alignment (46% improvement in history match quality without geologically implausible parameter adjustments), and enables previously sub-economic opportunities to achieve investment sanction thresholds. The Asset D case study provides unambiguous validation: Well D-44, ranked 9th under legacy architectural interpretation, was elevated to 2nd rank through recognition of inter-channel mouth bar compartmentalization, subsequently delivering 3.21 MMstb cumulative production within 6% of revised model forecasts and generating $18.2 million incremental net present value.

The key finding transcends the specific technical results: architectural element definition must be recognized not as a one-time exercise completed during field appraisal but as a dynamic, iteratively refined variable that directly influences decision quality throughout field life. This conceptual shift—from treating architectural frameworks as static inputs to operationalizing them as active control levers—represents a fundamental departure from conventional modeling practice. The five-stage workflow presented herein provides a structured, repeatable mechanism for implementing this shift: baseline model audit identifies performance anomalies symptomatic of architectural misconception; data-driven reinterpretation proposes revised element boundaries constrained by integrated evidence; static model re-population implements revised frameworks within geocellular constructs; dynamic calibration discriminates between competing interpretations; and decision-control formalism translates narrowed uncertainty into sanctionable opportunities. Critically, this workflow delivers value without requiring new data acquisition, demonstrating that substantial economic benefit resides in disciplined reinterpretation of existing datasets—a finding with immediate applicability to capital-constrained mature field portfolios globally.

The broader implication extends beyond improved reservoir characterization to transformation of the static geological model's organizational function. Conventional practice treats static models as passive repositories of geological knowledge—archives consulted during decision processes but not active participants in decision formation. The operationalized architectural re-definition methodology repositions static models as dynamic decision-control systems wherein geological understanding iteratively co-evolves with business requirements, uncertainty thresholds adjust as architectural clarity improves, and investment opportunities emerge or disappear in response to refined geological insight rather than merely to new data acquisition. This transformation aligns geological characterization with portfolio management principles, enabling geoscientists to demonstrate quantifiable value creation through improved decision robustness rather than through qualitative assertions of "better understanding."

Looking forward, the methodology's applicability extends substantially beyond hydrocarbon production optimization. Subsurface energy transition initiatives—particularly geological carbon dioxide storage site characterization and monitoring—face challenges directly analogous to those addressed herein: legacy geological models constructed for hydrocarbon exploration require reinterpretation to assess containment security, injection capacity depends critically on architectural element connectivity and compartmentalization, and investment decisions demand uncertainty quantification calibrated to regulatory risk tolerances and long-term liability assessment (Ringrose et al., 2021). The workflow's emphasis on integrated seismic-dynamic calibration, explicit architectural uncertainty representation, and threshold-based decision control translates directly to CO_2 storage contexts wherein containment assurance and injectivity forecasting govern project viability. Similarly, geothermal energy exploitation in clastic reservoirs, hydrogen storage in depleted fields, and enhanced water recovery from stressed aquifer systems all require architectural precision to predict fluid flow behavior and de-risk subsurface investments. The operationalized architectural re-definition framework presented herein provides a proven, transferable methodology applicable across this expanding spectrum of subsurface energy and resource management challenges, positioning geological characterization as a central pillar of the energy transition rather than a legacy discipline.

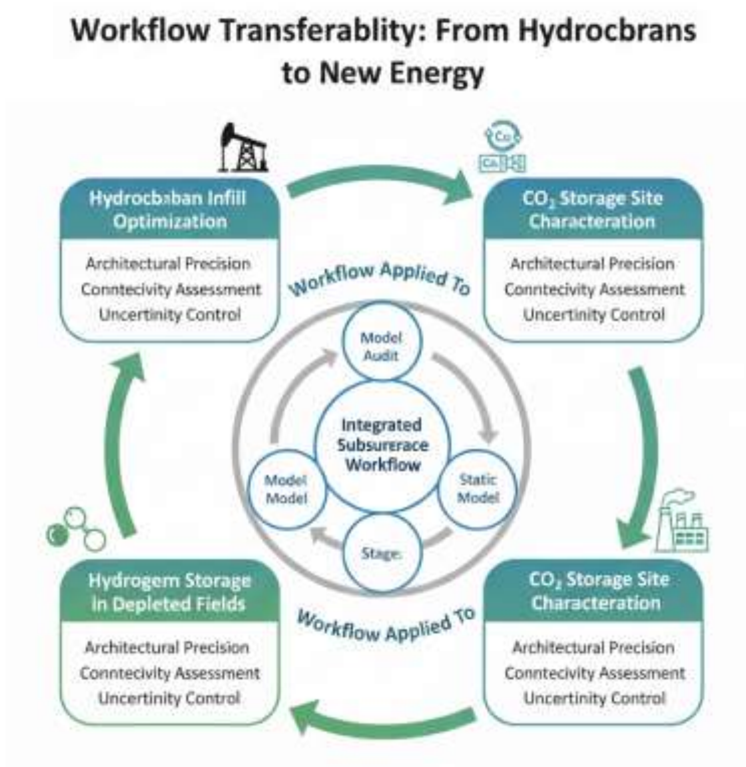

Figure: Workflow transferability: operationalized architectural re-definition methodology applicable across hydrocarbon optimization and subsurface energy transition applications requiring architectural precision and uncertainty control.

REFERENCES

Begg, S. H., Bratvold, R. B., & Welsh, M. B. (2014). Uncertainty vs. variability: What's the difference and why is it important? *SPE Hydrocarbon Economics and Evaluation Symposium*. https://doi.org/10.2118/169850-MS

Bentley, M., & Ringrose, P. (2015). Reservoir model design: A practitioner's guide. Springer.

Bhattacharjya, D., Eidsvik, J., & Mukerji, T. (2010). The value of information in spatial decision making. *Mathematical Geosciences*, *42*(2), 141–163. https://doi.org/10.1007/s11004-009-9256-y

Bickel, J. E., & Bratvold, R. B. (2008). From uncertainty quantification to decision making in the oil and gas industry. *Energy Exploration & Exploitation*, *26*(5), 311–325. https://doi.org/10.1260/014459808787945344

Bratvold, R. B., & Begg, S. H. (2010). Making good decisions. Society of Petroleum Engineers.

Caers, J., Hoffman, T., Strebelle, S., & Wen, X. H. (2006). Probabilistic integration of geologic scenarios, seismic, and production data—A West Africa turbidite reservoir case study. *The Leading Edge*, *25*(3), 240–244. https://doi.org/10.1190/1.2184090

Chopra, S., & Marfurt, K. J. (2007). Seismic attributes for prospect identification and reservoir characterization. Society of Exploration Geophysicists. https://doi.org/10.1190/1.9781560801900

Davies, R. J., Posamentier, H. W., Wood, L. J., & Cartwright, J. A. (Eds.). (2007). Seismic geomorphology: Applications to hydrocarbon exploration and production. *Geological Society, London, Special Publications*, *277*, 1–14. https://doi.org/10.1144/GSL.SP.2007.277.01.01

Demyanov, V., Kanevski, M., Chernov, S., Savelieva, E., & Timonin, V. (2010). Neural network residual kriging application for geological data. *Journal of Geographic Information and Decision Analysis*, *2*(2), 215–232.

Deptuck, M. E., Piper, D. J. W., Savoye, B., & Gervais, A. (2008). Dimensions and architecture of late Pleistocene submarine lobes off the northern margin of East Corsica. *Sedimentology*, *55*(4), 869–898. https://doi.org/10.1111/j.1365-3091.2007.00926.x

Deutsch, C. V. (2002). Geostatistical reservoir modeling. Oxford University Press.

Dreyer, T., Scheie, Å., & Walderhaug, O. (1993). Minipermeameter-based study of permeability trends in channel sand bodies. *AAPG Bulletin*, *77*(3), 359–374. https://doi.org/10.1306/BDFF8C26-1718-11D7-8645000102C1865D

Dubrule, O. (2003). Geostatistics for seismic data integration in earth models. Society of Exploration Geophysicists. https://doi.org/10.1190/1.9781560801962

Eidsvik, J., Mukerji, T., & Bhattacharjya, D. (2015). Value of information in the earth sciences: Integrating spatial modeling and decision analysis. Cambridge University Press. https://doi.org/10.1017/CBO9781139628785

Emerick, A. A., & Reynolds, A. C. (2013). Ensemble smoother with multiple data assimilation. *Computers & Geosciences*, *55*, 3–15. https://doi.org/10.1016/j.cageo.2012.03.011

Fanchi, J. R. (2010). Integrated reservoir asset management: Principles and best practices. Gulf Professional Publishing.

Geehan, G., & Underwood, J. (1993). The use of length distributions in geological modelling. In A. Flint & J. Bryant (Eds.), *The geological modelling of hydrocarbon reservoirs and outcrop analogues* (pp. 205–212). International Association of Sedimentologists Special Publication No. 15. Blackwell Scientific Publications.

Granjeon, D. (2014). 3D forward modelling of the impact of sediment transport and base level cycles on continental margins and incised valleys. In R. Martins-Neto & W. Bartorelli (Eds.), *Sequence stratigraphy: Applications to fine-grained rocks* (pp. 453–472). SEPM Society for Sedimentary Geology.

Hassall, J. K., Ferraris, P., Al-Harthy, S., Bloch, G., & Vielvoye, L. (2004). Comparison of permeability predictors from NMR, formation image and other logs in a carbonate reservoir. *Middle East Geosciences Conference and Exhibition*. Society of Petroleum Engineers. https://doi.org/10.2118/93240-MS

Hornung, J., & Aigner, T. (1999). Reservoir and aquifer characterization of fluvial architectural elements: Stubensandstein, Upper Triassic, southwest Germany. *Sedimentary Geology*, *129*(3–4), 215–280. https://doi.org/10.1016/S0037-0738(99)00103-7

Howell, J. A., Martinius, A. W., & Good, T. R. (2008). The application of outcrop analogues in geological modelling: A review, present status and future outlook. In A. Robinson, P. Griffiths, S. Price, J. Hegre, & A. Muggeridge (Eds.), *The future of geological modelling in hydrocarbon development* (pp. 1–25). Geological Society, London, Special Publications, 309. https://doi.org/10.1144/SP309.1

Jackson, M. D., Hampson, G. J., & Sech, R. P. (2009). Three-dimensional modeling of a shoreface-shelf parasequence reservoir analog: Part 2. Geologic controls on fluid flow and hydrocarbon recovery. *AAPG Bulletin*, *93*(9), 1183–1208. https://doi.org/10.1306/05110908145

Jégou, I., Savoye, B., Pirmez, C., & Droz, L. (2008). Channel-mouth lobe complex of the recent Amazon Fan: The missing link between submarine channel and sedimentation lobe. *Marine Geology*, *252*(1–2), 62–77. https://doi.org/10.1016/j.margeo.2008.03.004

Labourdette, R., & Jones, R. R. (2007). Characterization of fluvial architectural elements using a three-dimensional outcrop data set: Escanilla braided system, south-central Pyrenees, Spain. *Geosphere*, *3*(6), 422–434. https://doi.org/10.1130/GES00087.1

Lake, L. W., Johns, R. T., Rossen, W. R., & Pope, G. A. (2013). Fundamentals of enhanced oil recovery. Society of Petroleum Engineers.

Mayall, M., Jones, E., & Casey, M. (2006). Turbidite channel reservoirs—Key elements in facies prediction and effective development. *Marine and Petroleum Geology*, *23*(8), 821–841. https://doi.org/10.1016/j.marpetgeo.2006.08.001

Miall, A. D. (1985). Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. *Earth-Science Reviews*, *22*(4), 261–308. https://doi.org/10.1016/0012-8252(85)90001-7

Miall, A. D. (1988). Reservoir heterogeneities in fluvial sandstones: Lessons from outcrop studies. *AAPG Bulletin*, *72*(6), 682–697.

Miall, A. D. (1996). The geology of fluvial deposits: Sedimentary facies, basin analysis, and petroleum geology. Springer-Verlag.

Mutti, E., & Normark, W. R. (1987). Comparing examples of modern and ancient turbidite systems: Problems and concepts. In J. K. Leggett & G. G. Zuffa (Eds.), *Marine clastic sedimentology: Concepts and case studies* (pp. 1–38). Graham & Trotman.

Mutti, E., & Normark, W. R. (1991). An integrated approach to the study of turbidite systems. In P. Weimer & M. H. Link (Eds.), *Seismic facies and sedimentary processes of submarine fans and turbidite systems* (pp. 75–106). Springer-Verlag. https://doi.org/10.1007/978-1-4684-8276-8_4

Nordahl, K., Ringrose, P. S., & Wen, R. (2014). Petrophysical characterization of a heterolithic tidal reservoir interval using a process-based modelling tool. *Petroleum Geoscience*, *11*(1), 17–28. https://doi.org/10.1144/1354-079303-613

Oliver, D. S., & Chen, Y. (2011). Recent progress on reservoir history matching: A review. *Computational Geosciences*, *15*(1), 185–221. https://doi.org/10.1007/s10596-010-9194-2

Pickering, K. T., Hiscott, R. N., & Hein, F. J. (1995). Deep marine environments: Clastic sedimentation and tectonics. Unwin Hyman.

Plink-Björklund, P., & Steel, R. J. (2004). Initiation of turbidity currents: Outcrop evidence for Eocene hyperpycnal flow turbidites. *Sedimentary Geology*, *165*(1–2), 29–52. https://doi.org/10.1016/j.sedgeo.2003.10.013

Posamentier, H. W. (2004). Seismic geomorphology: Imaging elements of depositional systems from shelf to deep basin using 3D seismic data: Implications for exploration and development. In R. J. Davies, J. A. Cartwright, S. A. Stewart, M. Lappin, & J. R. Underhill (Eds.), *3D seismic technology: Application to the exploration of sedimentary basins* (pp. 11–24). Geological Society, London, Memoirs, 29. https://doi.org/10.1144/GSL.MEM.2004.029.01.02

Posamentier, H. W., & Kolla, V. (2003). Seismic geomorphology and stratigraphy of depositional elements in deep-water settings. *Journal of Sedimentary Research*, *73*(3), 367–388. https://doi.org/10.1306/111302730367

Posamentier, H. W., & Martinsen, O. J. (2011). The character and genesis of submarine mass-transport deposits: Insights from outcrop and 3D seismic data. In R. C. Shipp, P. Weimer, & H. W. Posamentier (Eds.), *Mass-transport deposits in deepwater settings* (pp. 7–38). SEPM Society for Sedimentary Geology. https://doi.org/10.2110/sepmsp.096.007

Pranter, M. J., Ellison, A. I., Cole, R. D., & Patterson, P. E. (2007). Analysis and modeling of intermediate-scale reservoir heterogeneity based on a fluvial point-bar outcrop analog, Williams Fork Formation, Piceance Basin, Colorado. *AAPG Bulletin*, *91*(7), 1025–1051. https://doi.org/10.1306/02010706102

Pyrcz, M. J., & Deutsch, C. V. (2014). Geostatistical reservoir modeling (2nd ed.). Oxford University Press.

Ringrose, P. S., & Bentley, M. (2015). Reservoir model design: A practitioner's guide. Springer. https://doi.org/10.1007/978-94-007-5497-3

Ringrose, P. S., Mathieson, A. S., Wright, I. W., Selama, F., Hansen, O., Bissell, R., Saoula, N., Midgley, J., & Saoul, N. (2021). The In Salah CO_2 storage project: Lessons learned and knowledge transfer. *Energy Procedia*, *37*, 6226–6236. https://doi.org/10.1016/j.egypro.2013.06.551

Saller, A., Werner, K., Sugiaman, F., Cebastiant, A., May, R., Glenn, D., & Barker, C. (2008). Characteristics of Pleistocene deep-water fan lobes and their application to an upper Miocene reservoir model, offshore East Kalimantan, Indonesia. *AAPG Bulletin*, *92*(7), 919–949. https://doi.org/10.1306/03310807110

Scheidt, C., & Caers, J. (2009). Representing spatial uncertainty using distances and kernels. *Mathematical Geosciences*, *41*(4), 397–419. https://doi.org/10.1007/s11004-008-9186-0

Sylta, Ø. (2004). Hydrocarbon migration modelling and exploration risk. [Doctoral dissertation, Norwegian University of Science and Technology]. NTNU Open. https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/238880

Taware, S., Park, H., Datta-Gupta, A., Bhattacharya, S., & Jafroodi, N. (2012). Well placement optimization in a mature oil field using streamline-based analytic sensitivity. *SPE Annual Technical Conference and Exhibition*. https://doi.org/10.2118/159096-MS

Thakur, G. C. (2006). Reservoir management maturity model. *SPE Annual Technical Conference and Exhibition*. https://doi.org/10.2118/103270-MS

Tyler, N., & Finley, R. J. (1991). Architectural controls on the recovery of hydrocarbons from sandstone reservoirs. In A. D. Miall & N. Tyler (Eds.), *The three-dimensional facies architecture of terrigenous clastic sediments and its implications for hydrocarbon discovery and recovery* (pp. 1–5). SEPM Society for Sedimentary Geology. https://doi.org/10.2110/csp.91.03.0001

Wynn, R. B., Cronin, B. T., & Peakall, J. (2007). Sinuous deep-water channels: Genesis, geometry and architecture. *Marine and Petroleum Geology*, *24*(6–9), 341–387. https://doi.org/10.1016/j.marpetgeo.2007.06.001