28th Annual GCSSEPM Foundation Bob F. Perkins Research Conference

December 7-9, 2008, Houston, Texas

Answering the Challenges of Production from Deep-Water Reservoirs: Analogues and Case Histories to Aid a New Generation

Program and Abstracts

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28th Annual Gulf Coast Section SEPM Foundation Bob F. Perkins Research Conference

2008

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Houston Marriott Westchase
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Edited by

Kevin Schofield
Norman C. Rosen
Deborah Pfeiffer
Sam Johnson

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Foreword

In spite of the great sophistication of the technology brought to bear on the collection and analysis of geological data today, particularly in the oil industry, geoscience as practiced by the majority of us remains an essentially empirical endeavour not that different from the science practiced by our forebears in the nineteenth century. They clopped around the country on horseback, collecting samples, comparing and contrasting with their own prior experience and that of others published in the journals of the day. They produced detailed descriptions, maps and cross-sections, and from these derived theories of how the earth had evolved to its observed state. We travel the globe from our desks, collecting rock samples and remote sensing data of a variety of sorts…seismic, gravity, electromagnetic, satellite imagery. And, in our turn we compare and contrast with the data of others and develop our own theories or build on those of others to explain how what we observe became so.

Every so often this stately empirical process is disrupted when a ground-breaker or iconoclast steps up and rearranges all of our carefully assembled facts to fit a new paradigm. Thus, the observations supporting the Expanding Earth hypotheses of the nineteenth through mid-twentieth centuries were re-ordered and refiled with some added data to support the theories of Continental Drift and its evolved form Plate Tectonics. The evolution of sedimentary basins by crustal downwarping in geosynclines filled according to Walther's Law has been replaced by the hypothesis of Sequence Stratigraphy, which elegantly explains a whole raft of prior observations by repackaging them in a "better" framework.

In these cases, and many, many more, our understanding and ability to interpret the geology we observe (directly or remotely) and place it in a contextual framework is almost entirely dependent on the use of analogs. "The best geologist is he who has seen the most rocks" holds as true today as it always has. Those who see furthest in the geological sciences stand not on the shoulders of Newton's Giants, but have scaled a swarming termite hill of analogs and descriptive examples built up patiently over the years. The GCSSEPM Research Conferences have a long and distinguished history over almost three decades of bringing analogs to the geoscience community, and this, the 28th, aspires to follow in that tradition.

The original aim of this Research Conference was to expand a little further the pool of analogs we work with in a particular area: that of the development and production of hydrocarbon accumulations hosted in deep-water rocks. There was a specific intent to follow up on the GCSSEPM Research Conferences of 1994 (Submarine Fans and Turbidite Systems, Sequence Stratigraphy, Reservoir Architecture and Production Characteristics - Gulf of Mexico and International) and 2000 (Petroleum Systems of Divergent Continental Margin Basins), both of which introduced new fields and new deep-water concepts. Specifically, it was hoped that we could persuade the authors of some of the classic papers on Gulf of Mexico and other worldwide deep-water fields introduced as discoveries or early producers in those conferences to return to present on how their early predictions had panned out, and how their babies had grown up. We even hoped to inveigle some engineers into joining in to share with us how their geoscience colleagues worked with them to resolve the growing pains. It was a deliberate attempt to tease out a more holistic picture of the producing reservoir than is often found in the trade journals of either geoscience, which as often as not feature "mere" static description; or engineering, which often emphasize analytical mechanics over causative geometry.

Alas, as the Scottish Bard had it, *"the best laid plans o' mice and men gang aft awry,"* and that grand scheme has been thwarted by a number of realities that became apparent as we solicited help from around the industry. The principal culprit, it seems, is a simple lack of time on the part of most of our professional colleagues. There is no denying that putting together a presentation of any sort for a 30 to 40 minute slot at a conference is both daunting and time-consuming…facts to be gathered and checked, co-authors to be considered, drafts and drafts edited and honed. Add to that the requirement for a full-blown written paper (and a poster if you please!) and most people living a regular 24-hour work-a-day life find it very difficult to get there. When to this one adds the measure of corporate rigor that accompanies most "permission to publish" processes, the number of conferences that most of us receive solicitations to attend and publish at, and the number of journals *also* vying for our attention, I suppose it is not surprising that it was an uphill struggle to find the requisite willing volunteers. In spite of the fact that, dammit, this conference was a *really* good idea that ought to have had everybody clamoring to join in!!

So, we backed off a little from the original grand design, and have followed a path similar to the 1994 and 2000 meetings, providing you with a smorgasbord of new analogs and new concepts, providing both the latest from some newly producing fields, and some new and exciting ideas from some of our academic colleagues who have been helping us to interpret our reservoirs for many years. Although we have not had the pleasure of visiting with some old friends, the papers on Holstein and Schiehallion in particular cleave closely to the spirit of the original intent.

The opening keynote address, from John Farrelly of BP, provides an overview of the lesson that is reiterated in many of the papers that follow: the successful development of deep-water fields depends on planning, data collection and interpretation, working in an integrated fashion and, yes, selecting and utilizing the appropriate analogs. This theme of the importance of choosing the correct analog, specifically the correct outcrop analog, is also pursued by David Stanbrook of Maersk Oil & Gas. He and a number of co-authors also provide examples of how outcrop analogs can be used to resolve and understand the seismic responses of a number of reservoir geometries through synthetic seismic modeling. The synthesis of analog studies to provide a more statistical view of deep-water reservoir behavior is presented by Cossey and Studlick.

The original challenge of an introduction to some new fields and new concepts has been admirably taken up by authors presenting papers from both the Gulf of Mexico and Western Australia.

Form the Gulf of Mexico, Allen Mattis (Total) describes the development history of one of the newest subsalt discoveries at Tahiti, soon to come on production. A little further along the reservoir life-cycle, colleagues from Australia cover the recently-inaugurated Stybarrow and Enfield oil fields and the large gas static resource at Scarborough. In the Enfield case, Mee and Meckel (Woodside Petroleum) provide a thorough description of a slope turbidite field that was recognized from early in its development history as likely to be a challenging resource to develop.[1] The understanding of the field has been enhanced by the acquisition of a 4D seismic program that, even in its early stages, has yielded considerable fruit in terms of understanding and being able to predict the behavior of the reservoir. In a case history of the adjacent Stybarrow Field, Hill *et al.* (BHP Billiton Petroleum) describe the appraisal and development history of another slope turbidite accumulation, including a brief description of the characterization of the reservoir through a stochastic inversion. This theme is taken up again in more detail in the paper on Stybarrow and Scarborough by O'Halloran *et al*. (BHP Billiton Petroleum)

The theme of "learning during early development" is also taken up in papers on two further fields early in their production history. Wiseman *et al*. (BP) discuss the Holstein field, a supra-salt accumulation in the Gulf of Mexico where an understanding of early production behaviour provided vital clues to constrain the rebuilding of the initial reservoir model and forward planning of the ongoing development program. A similar story of complexity better defined during early production and the development of more sophisticated models is told by Taylor *et al*. (BG) for the Sapphire Field in the Nile Delta. Moving on down the asset producing life, Davey *et al*. (BP) describe the "middle age" of the giant West-of-Shetland Schiehallion Field in the UK. This is a logical follow-on to the descriptions of Stybarrow, Enfield and Holstein, describing a case where the "easy oil" has been accessed, and continued success depends on an increasingly sophisticated understanding of the interaction of pressure behaviour, geological complexity and fluid movement.

Somewhat more theoretical studies of reservoir complexity and how it can be described and accounted are presented in papers by McCaffrey *et al*. (U Leeds) describing the complex mass flow reservoirs of the Cretaceous Britannia Sandstone of the North Sea, and Haughton *et al*. (UC Dublin) who cover similar ground describing the necessity to understand the context of reservoir deposition in a basin, and how the geometry of any given reservoir is controlled ultimately by the behaviour of the flows that deposited it.

Returning to the use of outcrop analogs to provide both a contextual framework and a geometric description for understanding deep-water reservoirs, keynote presentations by Gardner *et al*. (Montana State) and Bernhardt *et al*. (Stanford) discuss outcrop data from West Texas and Chile, respectively. The latter paper describes the geometrical evolution of a foreland succession with associated facies evolution and analog scales. The paper by Gardner *et al*. provides a synthesis of many years of work on the classic Brushy Canyon outcrops, drawing the work together to

1. Unfortunately, a permissions problem resulted in the last-minute withdrawal of the full paper and presentation as we went to press. The abstract, with references for those wishing more detail, is included at the end of this volume.

describe a new hierarchical stratigraphic model that can be used as a framework for the prediction of sedimentary architecture…bringing us back to the opening discussion of the contextual paradigms within which we use our analogs to make predictions. The paper by Lerch *et al*. (BHP Billiton Petroleum) applies this new stratigraphic model to an area in the Gulf of Mexico.

In summary, the 28th GCSSEPM Research Conference follows proudly in the footsteps of those that have gone before, not so much standing on their shoulders but working diligently to add an extra increment to the termite mound, contributing to the stock of analogs that help all of us do our work better, providing some more rocks without which none of us can hope to become better geoscientists.

As convener of the conference, I would just love to take credit for all that lays before you. Modesty, integrity, and most of all the likelihood that I will be lynched by the myriad of people who have helped along the way, however, prevent me from doing so. First and foremost, I express my gratitude to the authors of the eighteen papers presented herein. They have, collectively, produced a cohesive and informative collection of new analogs and ideas that will be of great value to their peers all around the industry. Some of them (OK, one of them) even managed to do so by the original deadline. I take my hat off to their professionalism and willingness to share their knowledge, notwithstanding the obstacles of time, corporate approvals, and competing venues. My thanks also to the Trustees of the Foundation, particularly Chairman Norman Rosen, who supported the theme from the get-go, displayed considerable faith in our ability to deliver on the promise even when it looked as if there wouldn't be enough "volunteers" to fill the program, and who has been a great support in the editing of the papers that make up the final volume. Norm…I apologize unreservedly for the odd occasion when the combination of the day job, the travel schedule, and my sublime conviction that it would all be alright on the night caused the teeniest bit of friction to creep into our dialog. My friends and colleagues Deb Pfeiffer (BHP Billiton) and Sam Johnson (BP) also provided editorial support, and my thanks also are due to Paul Weimer of UC Boulder and Mike Sweet of ExxonMobil and Andy Pulham, all of whom worked hard shaking the bushes to drum up papers. Honorable mention is also due to Brad Prather (whose paper made a gallant dash through the first quarter mile, only to fall at the first corporate approval fence) and Tim Garfield, both of whom attempted in vain to squeeze papers from the stone of their respective employers. My considerable gratitude also goes to Gail Bergan of Bergan et al., Inc., who has worked far harder, far longer, and much closer to the meeting than she should have had to while compiling the abstracts and published volume.

However, gentle reader, you're here to enjoy the conference, not to read history. Go forth, listen, learn, and most of all enjoy adding our offering to your stock of analog stories. You'll be the better geoscientist for it.

Kevin Schofield

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Houston Marriott Westchase
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Program

Sunday, December 7

4:00–6:00 p.m. Registration (Grand Foyer) and Poster Setup (Grand Pavilion)
6:00–8:00 p.m. Welcome Reception and Poster Preview (Grand Pavilion)

Monday, December 8

7:00 a.m. **Continuous Registration (Grand Foyer)**
7:45 **Welcome remarks, Mike Nault (Chair of the Board of Trustees, GCSSEPM Foundation) (Grand Pavilion)**

Session 1: Monday Morning
Characterizing and Dealing with Uncertainty

8:00 **Introductory remarks, Kevin Schofield (Conference Convenor)**

Keynote Address

8:10 .... *Preparing for Uncertainty: Why Front End Loading Matters in Predicting Reservoir Behaviour*
Farrelly, John

9:00 .... *Multi-Disciplinary Reservoir Description to Characterize Connectivity in a Complex Minibasin Fill—An Integrated Approach at Holstein Field*
Wiseman, Terry R.; Wagerle, Roger; Ballin, Paulo R.; Bump, Alex; McCaslin, Neil F. and Lederer, Mark

9:40 .... *Facies Characteristics in a Semi-Confined Basin: From High Net-to-Gross Channelized Sheets to Lower Net-to-Gross Onlap Margins: Grand Coyer Basin, SE France*
Stanbrook, David A., and Pringle, Jamie K.

10:20 Coffee

Session 1: Monday Morning (Cont.)
Characterizing and Dealing with Uncertainty

10:40 .... *Impact of Multiple Scales of Remobilization on Deep Marine Clastic Reservoir Architecture: The Aptian Britannia Sandstone Formation, North Sea*
McCaffrey, William D.; Eggenhuisen, Joris; Haughton, Peter D.W.; Butler, Robert W.H.; Barker, Simon P.; Del Pino Sanchez, Adriana; Archer, Stuart; Colleran, John; Hakes, Bill; Moore, Ian; and Hailwood, Ernie

11:20 .... *Reducing Time and Risk in Reservoir Modeling by Avoiding Pitfalls in Outcrop Analogue Choice*
Stanbrook, David

12:00–1:30: Lunch

Session 2: Monday Afternoon
General Models and Statistical Analysis

Keynote Address

1:30 p.m. .... *Stratigraphic Models for Deepwater Sedimentary Systems*
Gardner, Michael H.; Borer, James M. ; Romans, Brian W. ; Baptista, Noelia; Kling, Erik K.; Melick, Jesse J.; Wagerle, Roger; and Carr, Mary M.

2:20 .... *Creation and Application of a 3D Synthetic Stratigraphic and Seismic Model Using Systematic Stratigraphic Principles and Realistic Rock Properties*
Lerch, Chris; Thompson, T.; Apps, Gill; Hayes, Ian; Leishman, Markus; Gardner, Michael H.; Stoughton, Dean; Glinsky, Mike; and White, Chris

3:00 .... *Characteristics of Worldwide Hydrocarbon Discoveries and Fields in Deep-Water Deposits*
Cossey, Stephen P.J., and Studlick, Joseph R.J.

3:40–4:00: Coffee

Session 3: Monday Afternoon
Use of Forward Models for Characterization

4:00 .... *Resolving Deep-Water Stratigraphic Traps: Forward Seismic Modeling of a Turbidite Onlap: Montagne de Chalufy, Gres D'Annot Formation, SE France*
Stanbrook, David A.; Pringle, Jamie K.; Elliott, Trevor; Clarke, Julian D., and Gardiner, Andrew

4:40 .... *Resolving Deep-Water Channel Architectures: High Resolution Forward Seismic Modeling of Turbidite Systems, Ainsa II Channel, Campodarbe Group, Northern Spain*
Pringle, Jamie K.; Stanbrook, David; and Clarke, Julian D.

5:30–8:00: Open Poster Session and Buffet Supper

8:00 Authors remove posters; contractor will start removing display boards at 8:15 p.m.

Tuesday, December 9

Session 4: Tuesday Morning
Taking Care of Business: Analogues and Characterizing Channel and Slope Reservoirs

8:30 a.m. **Introductory remarks, Kevin Schofield**

Keynote Address

8:40 .... *The Multi-Stage Evolution of an Elongate Submarine Fan Through an Axial Channel Belt to a Prograding Slope System: The Deep- to Shallow-Marine Fill of the Magallanes Basin, Chile*
Bernhardt, Anne; Jobe, Zane R.; Lowe, Donald

9:30 .... *Sapphire: Not Another Layer Cake*
Taylor, Katy; Folefac, Alex; Elsherbiny, Ahmed S.; Abonaem, Khaled; Fathy, Alaa, and Mohammed, Rehab E.

10:10 Coffee

10:50 .... *Development of a Slope Turbidite Reservoir: A Case History from the Stybarrow Field, Western Australia*
Hill, Robin; O'Halloran, Gerard; Elliott, Alison; Locke, Mark; Napalowski, Ralf, and Croft, Marion

11:20 .... *Managing and Mitigating the Midlife Stage of the Giant Schiehallion field, Tertiary Deepwater, West of Shetlands, UK*
Davey, Simon; Macdonald, Chris; Martin, Karen; MacGregor, Alan; Fletcher, John; Davies, Merv, and Pettigrew, Sara

11:50 .... *Integration of Model-Based Seismic Inversion (DELIVERY) in the Stratigraphic Interpretation of Turbidite Reservoirs from the Stybarrow Field and Scarborough Discovery, Western Australia*
O'Halloran, Gerard; Hill, Robin; Woodall, Mark; Goody, Angus, and Glinsky, Mike

12:20–1:45: Lunch

Session 5: Tuesday Afternoon
Taking Care of Business: Analogues and Characterizing Lower Slope and Basin-Floor Reservoirs

Keynote Address

1:45 p.m. .... *Sediment Gravity Flow Deposits and Bed-Scale Heterogeneity—Lessons from North Sea Fields*
Haughton, Peter D.W.; McCaffrey, William D.; Davis, C., and Barker, Simon P.

2:35 .... *Geological Challenges in Reservoir Modeling, Tahiti Field, Green Canyon 596/640, Gulf of Mexico*
Mattis, Allen F.

3:15 **Concluding remarks, Kevin Schofield**

GCSSEPM Foundation

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Cover Image

The cover image chosen for this year's conference is Figure 4 from Stanbrook et al.: "Resolving Deep-Water Stratigraphic Traps: Forward Seismic Modeling of a Turbidite Onlap; Montagne de Chalufy, Grès d'Annot Formation, Southeast France."

Preparing for Uncertainty: Why Front End Loading Matters in Predicting Reservoir Behaviour

Farrelly, John

Abstract

Reservoir performance prediction begins in the earliest phases of opportunity selection. In the Gulf of Mexico doing all things possible to inform and compensate for inherent subsurface uncertainty and related resource, rate and profile risks is particularly important. As we move to increasingly challenging developments, many key subsurface uncertainties will persist well after production commences. This is the result of complex petroleum systems, expense involved in collecting appraisal data, lack of dynamic data, and limited availability of robust production analogues. At a high level, there are three themes or focus areas that help shape performance prediction and address uncertainty therein.

Firstly, the right level of front end loading at each step from exploration idea to production is necessary. This begins with thinking about "developability" before exploring. Beyond volumes, what are the rate, well density, and overall cost ranges anticipated? Being deeply considerate of the value of information to be obtained in exploration and appraisal work is key to inform these parameters.

Next, analogue choice is critical and must go beyond rock properties to whole rock and fluid system analogues. Asking why we want an analogue really matters. Are there limits to the analogue relative to the diagenetic and structural overprints that may be anticipated?

The third theme is working in an integrated fashion to build flexibility into chosen development concepts.

This presentation will discuss how addressing these themes enables uncertainty to be more efficiently reduced and mitigated using examples from a number of Gulf of Mexico reservoirs.

Multidisciplinary Reservoir Description to Characterize Connectivity in a Complex Minibasin Fill—An Integrated Approach at Holstein Field

Wiseman, Terry R.
Wagerle, Roger
Ballin, Paulo R.
Bump, Alex
McCaslin, Neil F.
Lederer, Mark

Abstract

The Holstein reservoirs comprise a series of stacked Lower to Middle Pliocene turbidite sands with the field formed structurally by a large, steep, southeasterly dipping, monoclinal structure. Oil column heights exceed 2500 ft. Stratigraphic and structural complexity was documented through careful intra-reservoir mapping, seismic facies analysis and structural interpretations integrated with static and dynamic pressure data (build-up and interference tests). The integrated geologic analysis revises the existing Holstein geologic model for improved development planning and early production management.

The geological model developed at sanction described the unconsolidated reservoir sands as being deposited in a ponded, intraslope salt basin dominated by thick, high energy amalgamated reservoirs with internal homogeneity and excellent connectivity. Early performance suggested heterogeneities are more complex than originally envisaged. The reservoir architecture elements comprise sandy sheets and channels that shingle to form genetically related reservoirs. Static and dynamic pressure data, build-up tests, and interference tests suggest baffling between geobodies and pressure-isolated compartments between some shingles. Post-depositional modification of the reservoir further complicates well performance by removing reservoir entirely or reducing thickness. In addition, a structural overprint creates deformation bands which appear to reduce well productivity through reduction of effective permeability in the structurally steepest segment of the field.

A revised understanding of reservoir heterogeneity calibrated with dynamic data has allowed a greater understanding of variations in well performance. On a field scale the characterizations have been incorporated into a re-build of the reservoir model, which has created greater confidence in the depletion plan to optimize recovery.

Facies Characteristics in a Semi-Confined Basin: From High Net-to-Gross Channelized Sheets to Lower Net-to-Gross Onlap Margins: Grand Coyer Basin, SE France

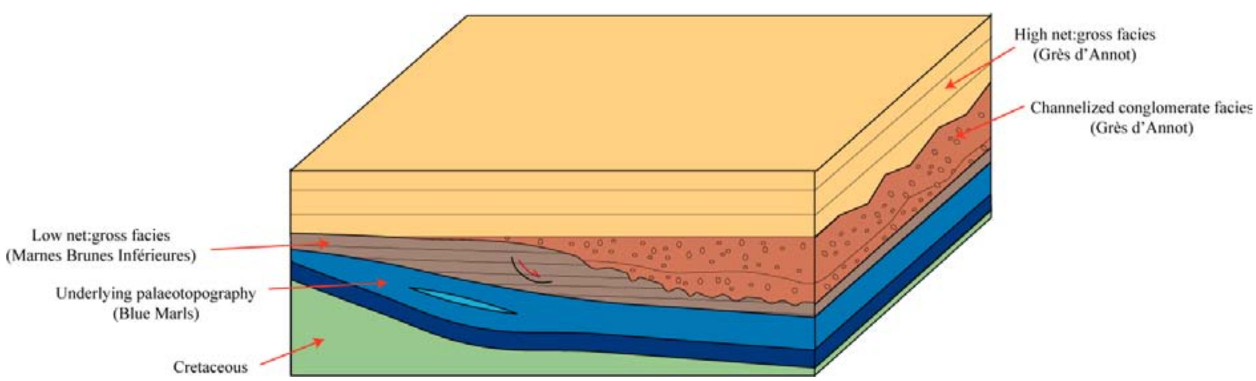
Stanbrook, David A.
Pringle, Jamie K.

Abstract

Common stratigraphic-trap reservoirs in the Gulf of Mexico and along the margins of the Atlantic are found within channelized (e.g. Tahoe) or basin margin settings (e.g. Auger, Mars). These are frequently within small, structurally controlled and topographically complex 'fill & spill' mini-basins; most often in salt-provinces. Both high net:gross channel and lower net:gross basin-margin environments occur concurrently in most basins and deciphering the lateral and distal relationships between these environments is key to understanding reservoir connectivity.

The Grand Coyer remnant (Grès d'Annot, SE France) demonstrates lateral and distal facies changes in a confined basin with complex paleotopography. Within the basin a relatively thin-bedded unit, the Marnes Brunes Inférieures (MBI) is interpreted as a distal and lateral equivalent of the thick-bedded Grès d'Annot (Stanbrook & Clark 2004). The MBI represents deposition away from the main axis of flow which is represented by the Grès d'Annot.

The finer grained facies of the MBI is shown to pre-date as well as to intercalate with the higher net:gross sections the Grès d'Annot in a lateral and distal sense. Also the bedding of the MBI is shown to onlap the underlying paleotopography, with higher net:gross Grès d'Annot, in turn, onlapping the MBI; these bedding discordances are often associated with slumping. The intercalation and bedding-discordance has implications for hydrocarbon charge, seal and lateral distal connectivity. Multiple examples of, and the relationships between, these facies are shown.



Schematic representation of erosional relationships between channelized, high net:gross Grès d'Annot and the thinner bedded Marnes Brunes Inférieures; one of several variations in facies relationships induced by complex topography.

Impact of Multiple Scales of Remobilization on Deep Marine Clastic Reservoir Architecture: The Aptian Britannia Sandstone Formation, North Sea

McCaffrey, William D.
Eggenhuisen, Joris
Haughton, Peter D.W.
Butler, Robert W.H.
Barker, Simon P.
Del Pino Sanchez, Adriana
Archer, Stuart
Colleran, John
Hakes, Bill
Moore, Ian
Hailwood, Ernie

Abstract

The Britannia Sandstone Formation in the Outer Witch Ground Graben of the North Sea comprises Upper Aptian deep-water sandstones. It has been extensively drilled and cored on and around the Britannia gas condensate field. The Britannia reservoir section thins and pinches out against a paleoslope formed by the Fladen Ground Spur to the North. In the past, the reservoir has been informally subdivided into a series of numbered reservoir zones, largely guided by biostratigraphy. On this basis, correlation within the lower half of the reservoir (sub zone 40) is extremely complex, whereas the upper half is broadly sheet-form and coherent. However, aspects of reservoir performance have proven difficult to reconcile with this geometric model - but these can now be related to remobilization effects at a variety of scales linked to instability associated with the confining Fladen Ground slope. Until recently, the lower half of the reservoir was thought to represent a sequence of *in-situ* turbidite beds alternating with a series of moderate-scale debris flow deposits. However, detailed mapping in the Platform area of the field has shown that whilst wells in the North-west preserve a lower section that is intact with *in-situ* and correlatable sandstones, sections to the West and South-east are involved in large scale mass transport, and the sandstones are either disconnected blocks or have been homogenized and degraded by mixing with clay prone lithologies during remobilization. Previous zonal picks lie in or on the margins of debrite matrix sections between blocks. In the upper reservoir section, sheet sandstones have locally been duplicated, thinned or even excised by post-depositional sliding. One failure event (separating the zones 45 and 50 sheet sandstones) is associated with the down-dip emplacement of a thick olistostrome unit and debris flow that removed large sections of the underlying sandstone stratigraphy and emplaced large rafted blocks up to 10 m in thickness. The combined effects of this remobilization created an irregular base-of-slope topography with local relief estimated to exceed 15 m. The next turbidity current to enter the basin produced a deposit that essentially compensated for the preceding mass transport complex, with significant impact on modeled net-to-gross distribution. On a smaller scale within the upper reservoir section, syndepositional remobilization is thought to have caused local bed shearing, folding and inversion. A Remobilization Index has been applied that shows that the slope-adjacent sections are more prone to remobilization than slope-distal sections, and that the length scale of this variation can be defined. Limited reservoir production data suggest that reservoir performance may be in inversely-correlated with the degree of bed disaggregation identified by high indices of remobilization.

Reducing Time and Risk in Reservoir Modeling by Avoiding Pitfalls in Outcrop Analogue Choice

Stanbrook, David

Abstract

Geoscientists and engineers routinely apply outcrop analogues as an integral part of constructing geological models, and their use has become a common and useful tool in petroleum geoscience. Reservoir analogues are used at every stage of field life, from prospect development to maximizing returns in mature fields.

But how do we choose the correct outcrop analogue? For any given sedimentological environment there are dozens of well documented outcrops that may be used. Geoscientists and engineers must not only select analogues appropriate to the reservoir but consider the scale of the outcrop compared to seismic, petrophysical and other tools which may vary widely from one another. Combine the outcrop variables with sub-surface variables and the possibilities are almost limitless. Without investing a disproportionate amount of time in researching the multitude of outcrops and their characteristics, asset teams must find a way to collate, assess and distil key information. To collate detailed geometrical and architectural information on all, or even just major, outcrop types is time extremely time consuming.

Inclusion or elimination of analogues can be achieved by simultaneous evaluation of sub-surface and outcrop analogue data from a depositional system model standpoint. This allows the geologist to map what is known about their prospect onto what is known about the outcrops. A well selected depositional system model acts as the bridge between the two allowing initial selection, and more importantly, de-election of analogues.

An example of a systematic and consistent approach to outcrop analogue choice is given. Through the use of depositional models it is possible to make critically derived choices about which analogues to use. It also allows the proper elimination of which analogues not to use, thus freeing time to focus on those analogues that are most relevant.

Stratigraphic Models for Deepwater Sedimentary Systems

Gardner, Michael H.
Borer, James M.
Romans, Brian W.
Baptista, Noelia
Kling, Erik K.
Melick, Jesse J.
Wagerle, Roger
Carr, Mary M.

Abstract

Stratigraphic models predict sedimentary architecture. Prediction requires understanding systems in sufficient detail to permit identification and quantification of the process-response relationships that define them. For deepwater sedimentary systems this includes understanding the controls on sedimentary body emplacement, the geomorphic hierarchy of body types, the process linkage between the channel fill and flanking deposits, and how depositing flows evolve and transform across shelf-to-basin profiles. Because thickness, lithology and sedimentary body type all vary through a diachronous episode of deepwater sedimentation, these changes can be used to define phases in system evolution. These sedimentation phases reflect energy changes within the sedimentary system, which are driven by both external (allogenic) and internal (autogenic) controls.

Shelf-to-basin studies of the Brushy Canyon Formation demonstrate that the more complete basinal record correlates to a fragmented shelf record, with this incongruity impacting recognition of allogenic forcing. As the ultimate sediment sink, the external controls are best resolved from the deepwater record, but internal changes in local gradient and topography also impact sedimentation. This can make it difficult to differentiate between external controls without complete characterization of the basin. Despite these challenges, two stratigraphic models have been developed to predict patterns of deepwater sedimentation. Though derived from Middle Permian Brushy Canyon cycles mapped in outcrop and correlated across the Delaware Basin, the models have been tested against many other systems and basins.

Tectonics and climate combine to modulate sediment supply and sea level, which are considered the principal allogenic controls on sedimentation. Allogenic controls moderate system energy during a diachronous episode of deepwater sedimentation described by the phases of the AIGR (pronounced "Eiger," after the Swiss mountain) stratigraphic model. Unlike the phases of sea level change correlated in sequence stratigraphy, the AIGR model emphasizes deepwater system energy recorded in the basin. A complete AIGR cycle of sedimentation commences with the *Adjustment* phase, which defines the important initial conditions of profile gradient and topography. This phase can be represented by a surface, e.g., an unconformity, a mass transport event, or be recorded by lithology and/or architectural changes. The *Initiation*, *Growth*, and *Retreat* sedimentation phases represent important depositional phases that record changes in system energy, gradient, and sediment supply at multiple scales within a basin. These depositional phases characterize architectural and lithology changes and thickness distributions within a hierarchy of stratigraphic cycles.

Sedimentation generates topography, which shifts deposition laterally and transforms active sedimentation sites into inactive ones. This repetitive pattern of sedimentation generates cyclic facies successions of limited extent, which are referred to as autogenic cycles. In deepwater systems autogenic cycles can be generated by the retrogressive failure of slumps, by the lateral offset and compensational stacking of lobes, by channel switching, migration and avulsion, and by longitudinal translation of the channel-lobe transition zone.

The architecture of channel and channel-related bodies reflects migration patterns of the channel-lobe transition zone described by the *Build-Cut-Fill-Spill* (BCFS) stratigraphic model. These sedimentation phases can produce a sheet-channel-sheet architecture that varies with longitudinal profile position (gradient) and degree of confinement. Channel-fill, channel-flank and lobe sedimentary bodies represent building blocks that vary in proportion and arrangement in each phase. The BCFS model for submarine channels is embedded within the AIGR basin model and together they emphasize the correlation of a hierarchy of internally and externally generated stratigraphic cycles.

The AIGR and BCFS models correlate stratigraphic cyclicity to sedimentary architecture. They describe the systematic increase and decrease in sedimentation energy recorded in stratigraphy. The models are flexible because not all four energy phases defined in each model needs to be present for its application. In their complete form, the models recognize four sedimentation phases that generate distinct styles of sedimentary architecture and that may repeat and can be linked to changes in accommodation space and sediment flux.

Creation and Application of a 3D Synthetic Stratigraphic and Seismic Model Using Systematic Stratigraphic Principles and Realistic Rock Properties

Lerch, Chris
Thompson, T.
Apps, Gill
Hayes, Ian
Leishman, Markus
Gardner, Michael H.
Stoughton, Dean
Glinsky, Mike
White, Chris

Abstract

Datasets from hydrocarbon discoveries in deep-water stratigraphy in the Gulf of Mexico have served as the basis for the creation of a 3D synthetic stratigraphic and seismic model. Datasets included thick vertical sections of turbidite stratigraphy and good quality 3D seismic images. Creation of the model served as a quantitative way to apply systematic stratigraphic principles derived from outcrop and subsurface studies, as well as a way to predict variation in local reservoir quality and properties. In addition this work was able to measure the ability of seismic data to detect such variations. In this case the seismic detectability was relatively subtle.

The full clastic system at these discoveries encompasses 15-25 Ma and equates roughly to one second-order sequence stratigraphic cycle. This interval has been split into three third order cycles, each *c.*2 to 10 Ma. Seismic character and well log analysis of the turbidite system defined vertical and lateral variation in reservoir geometries (for example, axial fairway versus lobe versus lobe fringe patterns) and properties (such as bed thickness, net/gross, sorting, and permeability). A general stratigraphic framework and facies model from the Brushy Canyon Slope and Basin industry consortium was applied to the dataset to predict the shape and size of third through fifth order stratigraphic bodies, and the evolutionary variation of such bodies. This stratigraphic model, known as the "AIGR" model, characterizes the evolution of a stratigraphic system through an initial slope adjustment phase, followed by initiation, growth, and retreat phases of a turbidite system itself.

The basic and easily modifiable building block used in this synthetic model creation was a "channel-levee" pattern where the length and width of a central channel element, the length and width of flanking levee elements, and the size of the combined pattern was varied. A sheet element was a special case of this pattern where the "channel" was very wide and long and the flanking levees non-existent. The automation of body number, placement, size, shape, and reservoir property assignment was facilitated by a driving parameter called the "retreat index". This index parameter was set to vary in a cyclic fashion within the context of the lower-order system initiation/growth/retreat cycle, thereby driving systematic variation in all the other parameters.

The second to third order description of the model in three dimensions was constrained by the primary seismic markers mapped on the actual seismic data and penetrated by the well control through the turbidite system. Depth and time models were built in tandem, using appropriate sub-regional time-depth functions. Fourth and fifth-order body placement was done by allowing randomly generated body centers confined by a probability function defined by isochore thickness of the interval being populated.

Following creation of the synthetic model geometry and property variation a number of synthetic seismic volumes, derived volumes, and attributes were calculated. In addition many of the volumes were stratigraphically flattened to allow easier display of layer-based lateral variation.

Characteristics of Worldwide Hydrocarbon Discoveries and Fields in Deep-Water Deposits

Cossey, Stephen P.J.
Studlick, Joseph R.J.

Abstract

In early 2006, a study of the characteristics of deep-water fields and reservoirs was completed by the authors (Cossey and Studlick, 2007). Since that time, 73 discoveries have been added to the worldwide inventory of deep-water fields. Most of the newer discoveries have been made in Gulf of Mexico, but other notable discoveries have been made in China, India, Brazil, Mexico and West Africa. This paper provides an updated set of statistics, plots and characteristics of the 945 deep-water discoveries around the world and a comparison with the conclusions from a similar study completed almost 3 years ago.

More than 945 discoveries with total reserves >150 billion barrels of oil equivalent (BBOE) have been made in deep water deposits. A rapid increase in such discoveries began in the 1970s, corresponding to the advent of exploration in the North Sea and the early successes in the Campos Basin of Brazil. Based on historic trends, 300 are expected this decade.

More than 84% of the discoveries are in offshore basins. North America dominates the number of total discoveries as well as reserves, but there are an increasing number of discoveries in Africa and Asia. Reservoir rocks range in age from Ordovician to Pleistocene. However, more than 90% of discovereis are in Cretaceous or younger rocks. Passive margins have been the tectonic setting for most of these accumulations, and most are in slope depositional environments. Further statistics on hydrocarbons types, reservoir drives, trap types, porosity, and hydrocarbon column heights are presented from a database compiled by Cossey and Associates Inc.

Resolving Deepwater Stratigraphic Traps: Forward Seismic Modeling of a Turbidite Onlap: Montagne de Chalufy, Gres D'Annot Formation, SE France

Stanbrook, David A.
Pringle, Jamie K.
Elliott, Trevor
Clarke, Julian D.
Gardiner, Andrew

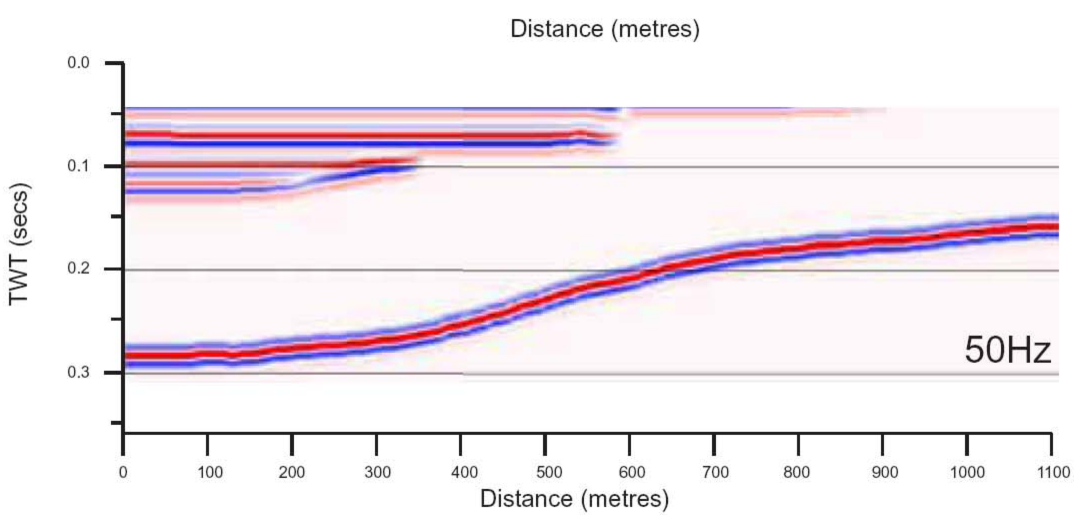
Abstract

The Gulf of Mexico and other salt/structural provinces are well known for stratigraphic traps within up-dip deep-water clastic sequences within a basin fill. Understanding the stratigraphic relationship between these sequences and underlying depositional slopes are critical to understanding charge and seal. This relationship is hard to resolve seismically, particularly in salt provinces where overlying salt-bodies may obscure finer-scale relationships that are key to reservoir seal. Lack of seals below seismic-resolution may act as potential 'thief zones' for hydrocarbons. In these circumstances outcrop analogues can provide examples of true onlap relationships and aid understanding to what the seismic expression may be.

The Montagne de Chalufy is a spectacular, seismic-scale outcrop. The section has been field investigated, interpreted, digitized and modeled, to generate forward seismic 2D sections. Three parameters were investigated: impedance contrast, model detail and wavelet frequency. Typical velocity and density values were taken from published producing reservoir data for observed lithologies.

Three seismic impedance scenarios were represented: Plio-Pleistocene Gulf of Mexico, Tertiary North Sea and Jurassic North Sea. Two levels of model detail were investigated, i) a detailed model to test seismic resolution and, ii) a simple onlap model without structural and sedimentary complexities. Two dominant Ricker wavelet frequencies were chosen, 26 and 50 Hz.

Results show outcrop analogues of turbidite sandstone reservoirs may be usefully converted to forward seismic sections. Model sections generated from high frequency wavelets allow interpretations that almost replicate detailed geological models. Gross architectures of massive, onlapping, turbidite sandstones may still be resolved in low frequency seismic datasets.



Forward seismic 2D section of the Montagne de Chalufy onlap section using Plio-Pleistocene Gulf of Mexico producing reservoir parameters.

Resolving Deepwater Channel Architectures: High Resolution Forward Seismic Modeling of Turbidite Systems, Ainsa II Channel, Campodarbe Group, Northern Spain.

Pringle, Jamie K.

Stanbrook, David

Clarke, Julian D.

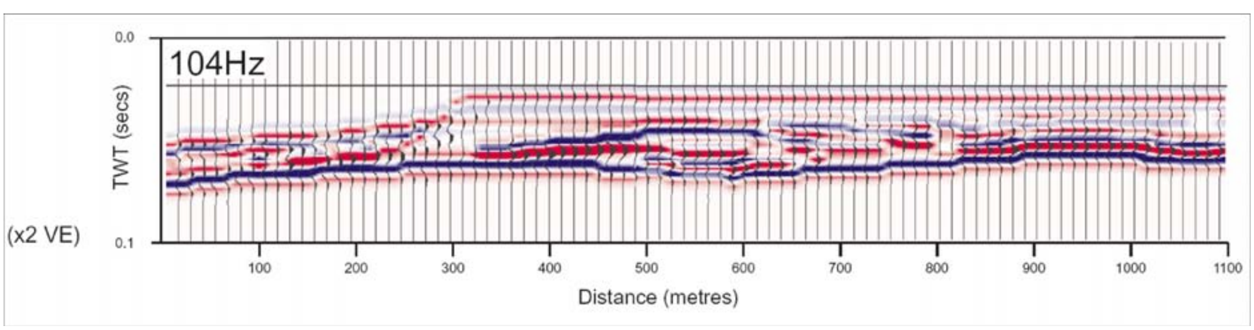
Abstract

Deep-water channels are of common interest in hydrocarbon exploration, however internal architectures and overall net:gross can be hard to resolve seismically. Channel-fill may range from high net:gross, back-stepping sheet-like geometries, multiple re-incisions to mass-transport complexes or passive infill. Interpreting this complexity is crucial in predicting reservoir fluid flow behavior. Seismic data are heavily relied upon for such interpretations. Outcrop analogues can provide examples of intra-channel geometric relationships and aid understanding of what the seismic expression may be.

The Ainsa II channel, Campodarbe Group, northern Spain is a spectacular exposure of slope conduits. The channel complex consists of five stacked channel units, characterized by distinct internal architectures. Forward 2-D seismic sections have been generated to investigate the effect that different rock properties and seismic frequencies have on resolving the channel complex geological detail.

Three seismic impedance scenarios were represented: Plio-Pleistocene Gulf of Mexico, Tertiary North Sea and Jurassic North Sea. A variety of dominant frequencies were used to investigate seismic resolution, representing those typically used for imaging deep and shallow reservoirs. Gamma Ray logs allow unit correlations and comparison to subsurface examples.

Results show that seismic images generated from low frequency wavelets (26Hz) do not resolve important heterogeneities within the channel complex. 52Hz sections suggest the target interval consists of stacked channels, although channel units are resolved. At 78Hz, an interpretation close to the geological model is achieved. Differing impedance contrast values have little effect on geological interpretations at the high signal:noise ratios used, although impedance values from North Sea Jurassic reservoirs yield the highest amplitudes in the synthetic sections.



Forward seismic 2D section of the Aina II channel complex using Plio-Pleistocene Gulf of Mexico producing reservoir parameters.

The Multistage Evolution of an Elongate Submarine Fan Through an Axial Channel Belt to a Prograding Slope System: The Deep- to Shallow-Marine Fill of the Magallanes Basin, Chile

Bernhardt, Anne
Jobe, Zane R.
Lowe, Donald

Abstract

The late Mesozoic to early Tertiary Magallanes foreland basin in southernmost Chile formed when regional shortening related to the Andean orogeny caused the inversion of the earlier Rocas Verdes back-arc basin into a retroarc foreland basin during the Late Jurassic. This inversion, the orogeny, and the onset of deep-water sedimentation is recorded by the ~1000 m thick Punta Barrosa Formation (Turonian-Coniacian) characterized by 40-150 cm-thick, generally medium-grained, tabular, turbiditic sandstone beds that alternate with abundant shale, sandy slurry flow and debris flow deposits. Sedimentation style changes during deposition of the overlying Cerro Toro Formation (Coniacian-Campanian), which consists of thick successions of thin-bedded mudstone and sandstone turbidites and debris flow deposits interrupted by thick (up to 400 m) deep-water channel complexes. The channels are filled with conglomeratic turbidity current deposits, conglomeratic slurry flows, and thick-bedded turbidite sandstone. Sediment transport was dominated by a 5-8 km wide axial channel belt with southward directed paleocurrents. Potential tributary channel complexes, possibly confined behind a local structural high, seem to have funneled sediment into the axial channel. In contrast, the overlying Tres Pasos Formation (Campanian) comprises marine slope deposits that represent southward progradation into the basin. Turbiditic sandstones at the base of the formation are overlain by abundant mass transport deposits and fine-grained turbiditic strata. Seafloor topography created by mass transport deposits affects the distribution of turbidity currents and their subsequent deposits. The transition from slope deposits into shallow marine sediments is recorded by the Dorotea Formation.

Due to its back-arc heritage, the Magallanes basin remained within the deep-water environment for ~ 15 Ma; however, depositional ages are still poorly constrained. Sedimentation style of the deep-water basin fill varies significantly throughout the three formations and the basin fill eventually shoals upward into shallow marine and deltaic deposits. The sculpting of the outcrops by recent glaciation provides superb exposure of the basin fill, making the Magallanes basin an excellent field area to study foreland basin evolution.

Sapphire: Not Another Layer Cake

Taylor, Katy
Folefac, Alex
Elsherbiny, Ahmed S.
Abonaem, Khaled
Fathy, Alaa
Mohammed, Rehab E.

Abstract

A key step in successful development planning and subsequent reservoir management is the construction of detailed geocellular models which capture the principle heterogeneities exhibited by the reservoir whilst also addressing uncertainty. Current work flows within the off-shore Nile Delta, WDDM concession rely heavily on the extraction of 3D seismic attributes to identify the main depositional elements and correlated to petrophysical properties.

The Lower Pliocene Sapphire Field is made up of a series of laterally extensive sheet-like reservoirs forming a stacked system of up to five pay intervals over a 400m thick section. In this respect it is unlike almost all of its WDDM counterparts which comprise largely canyon-confined sand-systems.

The pre-development, and largely simplistic layer-cake view of this field, which could have been carried through using the existing seismic workflows, has been re-assessed using data acquired during the drilling of 8 development wells, the detailed seismic mapping at both layer and sandbody scale and an integrated G&G-reservoir engineering approach to the history matching phase.

The relatively thin-sheeted nature of the reservoir means that unlike other WDDM reservoirs seismic attribute volumes cannot be simply transformed to particular reservoir parameters. The problem is compounded by the stacked nature of the reservoirs, which introduces some degree of seismic masking, and the presence of a gas chimney.

Seismic analysis at the sandbody-scale reveals a higher level of complexity than evident in the mid–upper Pliocene canyon-fill reservoirs, with sand sheets having multiple origins (splays, 'lobes', single sandy/muddy channels) and channels being dominated by heterogeneous sheet and splay deposits. This depositional complexity and the absence of clearly defined channel, belt and overbank areas combined with the unpredictable relationship between average amplitude and NHCPT has led to a more sedimentological driven model. Although this appears to move away from the current trend of simplifying reservoir models the heterogeneous nature of the Sapphire Field is born out by history matching and indicates that, certainly for reservoirs like Sapphire, a comprehensive modeling approach is appropriate.

Development of a Slope Turbidite Reservoir: A Case History From the Stybarrow Field, Western Australia

Hill, Robin
O'Halloran, Gerard
Elliott, Alison
Locke, Mark
Napalowski, Ralf
Croft, Marion

Abstract

Key subsurface challenges are faced in the development of relatively thin slope turbidite reservoirs containing biodegraded oil with little or no aquifer support. Lateral reservoir variations have important implications for connectivity and therefore the optimal drainage of such fields. This paper documents a multidisciplinary approach applied during the appraisal and development of the Stybarrow Field, Western Australia; examining how the integration of data on a variety of scales, from seismic and well data, to geological analogues and bed boundary resistivity modeling, has enabled detailed 3D geological models to be generated to estimate connectivity and oil recovery. Good reservoir connectivity will be crucial for successful drainage and sweep of the field.

The Stybarrow Field is a moderately sized biodegraded oil accumulation reservoired in early Cretaceous slope turbidite sandstones of the Macedon Formation in the Exmouth Sub-basin. Excellent quality 3D seismic has enabled attribute mapping and probabilistic seismic inversion (DELIVERY) to be used to both estimate the net sand distribution of the reservoir and facilitate optimal well placement. The reservoir interval is extensively cored and comprises excellent quality, but poorly consolidated, sand rich turbidites and grain flow sandstones within a variable net-to-gross interval up to 20m thick. The field lies in >800m water depth and is being developed via an FPSO. Pressure support is required from field start-up via sub-sea water injection wells due to an expected lack of aquifer support. Horizontal production wells with high productivity indices are required for optimal drainage. Downhole sand control is being provided by a combination of open-hole gravel packs and sand screens.

The field began production in November 2008, four years and nine months from discovery and reached nameplate production capacity of 80,000bopd within three weeks.

Managing and Mitigating the Midlife Stage of the Giant Schiehallion field, Tertiary Deepwater, West of Shetlands, UK

Davey, Simon
Macdonald, Chris
Martin, Karen
MacGregor, Alan
Fletcher, John
Davies, Merv
Pettigrew, Sara

Abstract

The giant Schiehallion Field, West of Shetland, UK, is now entering its midlife period after nearly 10 years of production. Understanding the reservoir heterogeneity and complex flood front behaviour is now critical to future field management. The big seismically-defined pools have been accessed and the next phases of development will require ever more detailed and integrated geological, petrophysical and reservoir engineering work. Even though geophysical 4D surveys and production data have been routinely acquired in wells from field startup, several key pieces of reservoir behaviour have been difficult to capture in models. The initial production and injection data showed that reservoir compartmentalisation had been seriously under-estimated and recent development wells continued to yield surprises. A new approach was needed and by 2007 this was in active planning and implementation.

Experience West of Shetland shows that the seismic can be pushed hard for defining geological envelopes, connectivity and seismic facies regions to allow hybrid seismic-geological facies modelling (Loyal and Foinaven analogues show this well). A new detailed approach was completed on Schiehallion by late 2007. More than 300 seismic-scale geological bodies were mapped out and as a first pass were populated with sophisticated seismic net pay properties. Detailed geological studies including well log interpretation, core interpretations, and a revised and outcrop-grounded facies model have combined to generate a solid understanding of the geology of the field and together with innovative modelling techniques and workflows has proved successful in understanding the key geological uncertainties. Reservoir engineering efforts are primarily focused at the long term management of the waterflood and in evaluating the benefits of additional wells in the field. A major remaining uncertainty is the future water cut development in the field as this impacts the sizing of future production and subsea infrastructure. Further development options and base management decisions need to be robust to downsides and no upside opportunities can be missed.

A full suite of deterministic models is being built to capture all main uncertainties and the static and dynamic issues worked out and analysed. The outcome is a discrete range of deterministic STOIIP models and a suite of history-matched and prediction runs that also capture the true behaviour of the field. The final crunch to getting everything together is to integrate the modelling and analysis efforts with all available data, and to this effect in addition to outcrop-based ground-truthing, there will be full close-the-loop work done on the satisfactory simulation models through 3D and 4D synthetic seismic to tie everything back together.

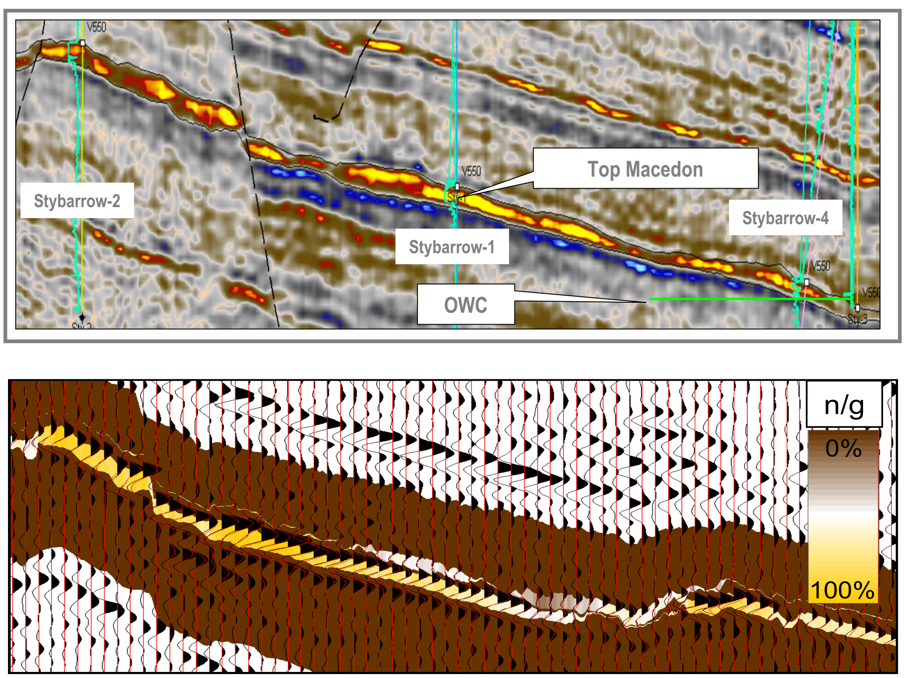
Integration of Model-Based Seismic Inversion (DELIVERY) in the Stratigraphic Interpretation of Turbidite Reservoirs from the Stybarrow Field and Scarborough Discovery, Western Australia

O'Halloran, Gerard
Hill, Robin
Woodall, Mark
Goody, Angus
Glinsky, Mike

Abstract

Model-based seismic inversion is increasingly recognized as being capable of providing an excellent quantitative reservoir framework for turbidite reservoirs. This paper explores how a new methodology for probabilistic model-based seismic inversions (DELIVERY) was used in a practical way throughout the development stages of the Stybarrow oil field and during the appraisal of the Scarborough gas discovery, both located in northwestern Australia.

Predictions of net sand were used in the case of Stybarrow to plan injector and producer wells, and to enhance post-drill stratigraphic interpretations that have subsequently been incorporated into detailed reservoir models. In the case of the more extensive Scarborough gas discovery, the extent of individual fan systems and their inter-relationships have been interpreted by incorporating inversion based predictions of sand thicknesses.



Seismic traverse along Stybarrow oil field,with accompanying Delivery-model-based inversion output for net-to-gross.

Sediment Gravity Flow Deposits and Bed-Scale Heterogeneity—Lessons from North Sea Fields

Haughton, Peter D.W.
McCaffrey, William D.
Davis, C.
Barker, Simon P.

Abstract

Conventional models for low and high-density turbidites provide a useful template against which vertical and lateral facies trends at bed scale can be assessed. However, such models are only appropriate for uniform, waning flows that become more dilute as they run out distally. Significant departures in both vertical and lateral texture and structure occur where flows show non-uniformity effects or undergo bulking, flow transformation and partitioning. The North Sea Basin contains a wide range of extensively cored and well characterised deep water systems of Jurassic, Cretaceous and Cenozoic age.

An important learning has been that conventional bed models do not apply to parts or all of many of these systems. Detailed study of bed-scale facies variations in slabbed cores have been critical in demonstrating alternative vertical facies trends – the complex structure of the finer grained lithologies is often difficult to see in all but wave-washed outcrops. The key building block in many reservoirs is a hybrid bed that captures longitudinal structure in the original flow involving transformation from frictional to increasingly cohesive behaviour.

The result is that clean reservoir sand is intimately interleaved with clay-prone sands at bed scale, particularly in distal and lateral sites where this can have a demonstrable impact on production. A variety of types of hybrid bed are apparent, and their variable expression is attributed to position, the scale of the system, the location of erosion, and the level of syn- to post-depositional soft-sediment deformation. As drilling extends into the deeper parts of other basins (e.g. offshore mid-Norway and the Gulf of Mexico) similar hybrid are being encountered.

Geological Challenges in Reservoir Modeling, Tahiti Field, Green Canyon 596 / 640, Gulf of Mexico

Mattis, Allen F.

Abstract

During the development of Tahiti Field a number of geological situations were encountered that required challenging and unique approaches to the Total E&P reservoir modeling. Steeply dipping pay sands, poor seismic resolution at the major pay sand level, and the presence of mud slumps that scoured away the updip edges of some of the pay sands near the rising salt-cored high to the west all complicated efforts to construct the Total E&P geological reservoir model.

Waterflood Performance and Time-Lapse Reservoir Characterization of Sand-Prone Mass Transport Deposits: Enfield Field, Canarvon Basin, Western Australia*

Mee, Ben
Meckel, Lawrence D.

Abstract

The Macedon reservoir sands of the Enfield field, Carnarvon basin, Australia are interpreted as outermost shelf to upper slope deposits. The lower Macedon sands represent the transgressive, shallow marine fill of valleys incised during lowstand, while the upper Macedon sands represent remobilized sediments (sandy mass-transport deposits) associated with the collapse of highstand shoreface and shallow marine systems into a deeper water setting.

Although the sands have excellent reservoir properties, stratigraphic and structural complexity and the characteristics of the fluid column (low structural dip, heavy oil with unusually low viscosity, gas cap, and limited aquifer) required a development plan that (i) minimized potential compartmentalization issues, (ii) maximized sandface exposure in development wells, (iii) prevented gas cap breakthrough, and (iv) allowed for rapid identification, monitoring, and correction of unexpected outcomes. The plan, which called for updip and downdip water injection and horizontal producers to minimize the risk of compartmentalization, also included the ability to monitor well and facility operating conditions in real time, an early monitor 4D survey, chemical tracers to monitor waterfront development, and history matching of dynamic reservoir models.

The start up and early reservoir performance of the Enfield development has been broadly consistent with that plan, allowing for a reduction in STOIIP which became apparent after the initial development drilling program was completed. All production wells achieved their initial design target rates, although sidetracks to the three horizontal wells were required to manage sand production. The water injection wells have all performed as expected and the four updip water injectors in particular have proved effective at preventing gas cap coning. Evidence to date from well performance data and reservoir surveillance data suggests that the waterflood is proceeding largely as expected. However, while many of the original reservoir development and management strategies have been vindicated, there have been also important practical learnings and insights.

Key learnings are that with a relatively small number of high rate production wells in a deepwater, frontier environment, effective sand control and completion reliability is crucial. Initial well and facility design should facilitate subsequent intervention and contingency plans supported by physical resources should be in place. Integration of key information in the early life of the Enfield water-flood development project led to improved understanding of the reservoir's architecture and dynamic behavior.

References

Ali, A., I. Taggart, B. Mee, M. Smith, A. Gerhardt, and L. Bourdon, 2008, Integrating 4D seismic data with production related effects at Enfield, North West Shelf, Australia: SPE Contribution 116916.

Hamp, R., B. Mee, T. Duggan, and I. Bada, 2008, Early Reservoir Management Insights from the Enfield Oil Development, Offshore Western Australia: SPE Contribution 116915.

Meckel, L.D., in review, Reservoir-prone mass-transport deposits: AAPG Special Publication.

Ridsdill-Smith, T., D. Flynn, and S. Darling, 2007, Benefits of two-boat 4D acquisition, an Australian case study: The Leading Edge, v. 27, p. 940.

Smith, M., A. Gerhardt, B. Mee, and L. Bourdon, 2008, Using 4D seismic data to understand production related changes in Enfield, North West Shelf, Australia: Preview, No. 132, p. 39-43.

Wulff, A., A. Gerhardt, T. Ridsdill-Smith, and M. Smith, 2007, The role of rock physics for the Enfield 4D seismic monitoring project: Exploration Geophysics, v. 39, p. 108–114.

* Oral presentation was withdrawn.

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