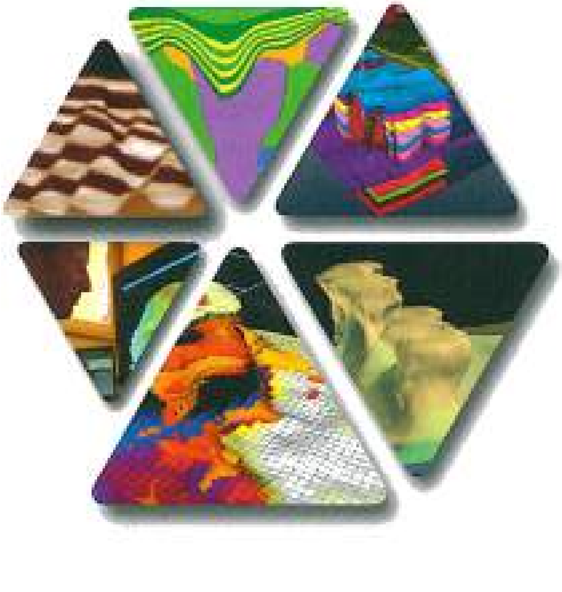
WORKSHOP

PSM 2017

IFP Energies nouvelles

Hotel Novotel, Rueil-Malmaison ■ 15 - 16 June 2017

Petroleum Systems Modeling workshop
Challenges of structurally complex basins



Abstract Volume

@IFPENinnovation

Context and Objective

This meeting is the first of a new series of biennial workshops dedicated to Petroleum Systems Modeling (PSM).

PSM has become a "commodity" of hydrocarbon exploration. Although PSM principles are now widely accepted and applied, many challenges remain. Increasingly complex basins are explored and subject to numerical modeling. Henceforth, multiple interacting physical processes, advanced specific mathematical computational methods and new integrated workflow taking uncertainties into account are a must. In practice, various and complementary fields of expertise come together to provide the basin modeling engineers with more effective and robust approaches, improved modeling workflow efficiency and prediction capability.

This workshop series aims to promote discussion and share experience in this field by gathering experts from international oil companies and bring together the highest level of skills from a range of disciplines.

This first meeting will focus on structurally complex basins for which modeling methodology and capabilities are still immature

www.psmworkshop2017.com

Organizing Committee

IFP Energies nouvelles, France

Marie-Christine Cacas-Stentz
Geosciences Division

Fadi-Henri Nader
Geosciences Division

Vincent Richard
Resources Business Unit

Steering Committee

Sascha Doering, Eni, Italy
Marek Kacewicz, Chevron, USA
Claudius Vandré, Statoil, Norway
Pierre van Laer, Adnoc, UAE
André Vayssaire, Repsol, Spain
Johannes Wendebourg, Total, USA

IFP Energies nouvelles

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins

Novotel, Rueil-Malmaison, 15-16 June 2017

Session 1 – Geodynamics and basin modeling

O/01 Influence of dynamic topography on the evolution of the Australian landscape since the Late Jurassic
T. Salles[1], N. Flament[2], R. D. Müller[1]
1 EarthByte Group, School of Geosciences, The University of Sydney, Australia ; 2 School of Earth and Environmental Sciences, University of Wollongong, Australia

O/02 Integrated analysis of seismic refraction and reflection, subsidence and thermal blanketing: implications for heatflow and charge modeling of the Exmouth Plateau, Northwest Australia
L. Kennan, C. Willacy, I. Brown, Shell, The Netherlands

O/03 The importance of lithospheric thickness as a boundary constraint on temperature prediction
S-A. Clark, R. Khabbaz Ghazian, Z. Tasarova, K. Hokstad, R. Kyrkjebø, Statoil, Norway

O/04 Thermal modeling in deep and ultra-deep offshore areas : from concepts to basin modeling practice
F. Lorant, C. Nielsen, Total, France

O/05 Fire and Ice: application of geodynamic thinking into petroleum system models
E. Hvidegård Hartz[1,2], S. Medvedev[2], D. W. Schmid[3], J. I. Faleide[2], K. Iyer[3], J. E. Skeie[1]
1 AkerBP, Norway ; 2 Centre for Earth Evolution and Dynamics, University of Oslo, Norway ;
3 GeoModelling Solutions, Switzerland

Session 2 – Towards coupling structural modeling, geomechanics and basin modeling

O/06 Integrated 2D seismic interpretation, geometrical forward modelling, 4D analogue modelling and discrete element modelling to determine the structure of a giant gasfield in the jungle-covered mountains of Papua New Guinea
Kevin Hill[1 & 3], R. Darnault[2], R. Wightman[1] and P. Rey[3]
1 Oil Search Ltd., Sydney, Australia; 2 IFPN France; 3 Basin Genesis Hub, School of Geosciences, The University of Sydney, Australia

O/07 From structural 3D restoration to petroleum system modeling
J-L Rudkiewicz, J. F. Lecomte, D. Colombo, I. Faille, IFPEN, France

O/08 Towards a coupled restoration/forward geomechanical modeling workflow for basin evolution prediction
A. J. L. Crook[1], J. Obradors-Prats[1], D. Somer[1], D. Peric[2],
1 Three Cliffs Geomechanical Analysis Ltd, Swansea University, UK ; 2 Swansea University, UK

O/09 Coupling petroleum system and geomechanics at basin scale
T. Cornu[1], A. Bouziat[2], D. Colombo[2], J. Frey[2], N. Guy[2], M-C. Cacas-Stentz[2]
1 Total, France ; 2 IFPEN, France

O/10 Fully coupled poro-mechanical basin models for pressure and effective stress prediction, with application to a mini-basin in voluminous salt
P. Lovely[1], M. Kacewicz[1], T. Crook[2] , J. Obradors[2]
1 Chevron, USA ; 2 Three Cliffs Geomechanical Analysis Ltd, Swansea University, UK

Session 3 – Integration of geopressure, geomechanics and seismic

O/11 Geophysical basin modeling: methodology and application in complex geological settings
G. De Prisco & al. Statoil, USA

O/12 Integrating basin modeling and rock physics to predict reservoir rock lithofacies and chemical diagenesis effects on overpressure
W. AlKawai, A. Hosford Scheirer, T. Mukerji, S. A. Graham, Stanford University, USA

O/13 Contribution of carbonate diagenesis to basin thermicity and barometry appraisal in sedimentary basins
M. Gasparrini & al. IFPEN, France

O/14 Basin modeling in 2D complex structural areas - Issues and existing solutions for the complex geological scenarii.
R.Darnault[1], T. Crabie[1],, R. Divies[1], J-F Lecomte[1], M. Callies[2]
1 IFPEN
2 Beicip-Franlab

Session 4 – Integrated basin modeling workflow

O/15 Workflow to model non uniaxial effects into uniaxial basin models at early stage exploration, while keeping the model as simple as possible
T. Harrold, S. Martinez, A. Vayssaire, P. Rouillé , O. Fernandez, Repsol, Spain

O/16 Secondary hydrocarbon migration in complex multi-carrier settings - some practical insights
S. Doering, S. Castellani, L.Baruffini, Eni Upstream & Technical Services, Italy

O/17 3D numerical stratigraphic forward modeling of rifts: characterizing reservoir presence risk
A. D. Harris[1], P. J. Lovely[1], S. E. Baumgardner[1], K. Ghayour[1], T. Engelder[1], T. Sun[1], R. P. Lyons[1], D. Granjeon[2]
1 Chevron, USA ; 2 IFPEN, France

-oOo-

ABSTRACTS

Abstracts are listed following the program order

The abstracts are published in their original format
as they were sent to the Organizing Committee

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Influence of dynamic topography on the evolution of the Australian landscape since the Late Jurassic

Tristan Salles1, Nicolas Flament2, R. Dietmar Müller1
1 EarthByte Group, School of Geosciences, The University of Sydney, Sydney, NSW 2006, Australia
2 School of Earth and Environmental Sciences, University of Wollongong, Northfields Avenue, Wollongong, NSW 2522, Australia

Australia is an outstanding natural laboratory to study the influence of dynamic topography on landscape evolution. Recent studies of the past eastern Australian landscape from present-day longitudinal river profiles and from mantle flow models suggest that the interaction of plate motion with mantle convection accounts for two phases of large-scale uplift of the region since 120 Ma.

We coupled dynamic topography predicted by **CitcomS** mantle flow model to **Badlands** surface process model to quantify the feedbacks between mantle flow, landscape dynamics and sediment transport at continental scale. We apply the approach to the evolution of the Australian landscape over the last 150 Myr.

We forced Badlands models with predicted dynamic topography, varying rainfall regime, erodibility, long-term sea level variations, dynamic topography magnitude and elastic thickness across a series of experiments. Badlands models quantify the time dependence of erosion and deposition, as well as the evolution of catchment dynamics, drainage capture and drainage network reorganisation. The predicted temporal and spatial changes in longitudinal river profiles as well as erosion and deposition maps show that the motion of the Australian plate over the convecting mantle resulted in significant reorganization of the eastern Australian drainage, continental-scale erosion and sedimentation. The model predicts that the Murray River drained eastward between 150 and 120 Ma, and switched to westward draining due to the tilting of the Australian plate from 120 Ma. First order comparisons of eight modelled river profiles and of the catchment shape of modelled Murray-Darling Basin are in agreement with present-day observations. The predicted denudation of the eastern highlands is compatible with thermochronology data and sedimentation rates along the southern Australian margin are consistent with cumulative sediment thickness. Despite the relative simplicity of our coupling approach, these promising results reflect the fundamental links between continental-scale dynamic uplift, and continental-scale drainage evolution and deposition.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Integrated analysis of seismic refraction and reflection, subsidence and thermal blanketing: implications for heatflow and charge modelling of the Exmouth Plateau, Northwest Australia

Lorcan Kennan[1], Chris Willacy[1], Ikae Brown[2]
[1] : Shell Projects and Technology, Amsterdam, The Netherlands
[2] : Shell Australia Pty, Perth, Australia

In early 2015 Shell acquired a refraction and reflection survey on the outer Exmouth Plateau, using OBS nodes provided by Geoscience Australia. Up to 18 km of sediment lies on slightly rugose, uniformly c. 6 km thick, basement with refraction velocities consistent with basaltic or gabbroic crust overlying normal to slightly altered mantle. What has previously been interpreted as transparent middle crust and laminated lower crust is clearly sedimentary, with characteristics of deposition in deep water, including slope instability and growth faulting, followed by shallowing and progradation of the Triassic Mungaroo Delta. Lithology inverted from a hybrid refraction-reflection velocity model and well data supports this interpretation, suggesting that the underlying crust is oceanic, of possible late Carboniferous to early Permian age. The overall Permo-Triassic setting is comparable to the modern Niger Delta.

Conventional backstripping methods show a c. 400 m negative depth anomaly in sediment-poor outboard areas, similar to the negative Miocene to recent dynamic topography observed in shallow water areas of the NWS. However, there is a c. 600 m positive anomaly in the area with thickest sediment. There is no associated free-air gravity anomaly, and refraction data preclude a cryptic substantially thicker crust to isostatically support the backstrip anomaly.

An integrated whole lithosphere basin model shows that the thermal blanketing effect of thick sediment on the underlying mantle matches the apparent subsidence discrepancy and resolves the differences between heatflow models inferred from observed seismic crust thickness, from backstripping and isostasy, or beta factors inferred from observed thermal subsidence. Our model matches available temperature and maturity observations well but the early thermal history is significantly hotter than these other methods would predict. We estimate palaeowaterdepth anomalies and show that Late Jurassic thermal doming, sill emplacement, uplift and erosion is associated with positive palaeo-dynamic topography independent of crustal thickness history.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

The importance of lithospheric thickness as a boundary constraint on temperature prediction

Stephen A. Clark[1], Zuzana Alasonati Tasarova[1], Ketil Hokstad[1], Rune Kyrkjebø[1]
[1]: Statoil Research Center, Trondheim, Norway

Accurate prediction of subsurface temperatures impacts many aspects of basin and prospect risking, from source rock maturity to reservoir quality to biodegradation. Standard basin modeling practice is to tune the temperature model to fit well observations (eg., temperature, vitrinite reflectance) by adjusting the basement heat flow maps, which provide a basal boundary constraint. This allows the basin modeler to perfectly match observations at the well locations, giving the impression of a robust temperature prediction. However, the most important locations for temperature prediction, namely prospects and source kitchens, are often far away from well control.

Either explicitly or implicitly, the fundamental basal boundary condition to the Earth's temperature model is the depth to the lithosphere-asthenosphere boundary (LAB). The LAB constitutes the mechanical boundary between asthenospheric mantle convection below and rigid lithospheric plate tectonics above. Consequently, it separates a regime dominated by conductive heat transport in the lithosphere from the advection-dominated asthenosphere. The thermal LAB is typically defined as an isotherm of 1350±100°C. Fourier's Law of heat conduction establishes an inverse relationship between heat flow and LAB depth.

Recent advances in seismic tomography (eg., Pasyanos et al., 2014; Steinberger and Becker, 2016) and petrological-geophysical mantle modeling (Afonso, 2006) allow for improved vertical and lateral resolution on the depth to the LAB. However, the relationship between the seismic and thermal LAB remains poorly understood. Nevertheless, if we assume a close correlation between the two, seismic LAB depth variations can provide useful constraint on heat flow trends away from well control, particularly in areas that are tectonically passive and approximately at thermal equilibrium through the lithosphere. We show two such examples to demonstrate the value of LAB depth in predicting lateral heat flow variations.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Thermal modeling in deep and ultra-deep offshore areas: from concepts to basin modeling practice

François LORANT, Charlotte NIELSEN
TOTAL E&P, Paris, France

For the past few years, oil and gas exploration of passive margins has extended to distal and ultra-distal areas, raising numerous challenges for geoscientists and engineers. One of these stakes is to predict the thermal evolution (therefore, the timing of potential petroleum systems) in such geodynamically complex settings, where little data exist and very few wells have been drilled to date.

Petroleum system modeling has been originally designed for sedimentary basins dominated by vertical movements, with a thermal evolution that can be represented by a 3-layer lithosphere governed by McKenzie principles. Even though, in the recent years, additional capabilities have been proposed by software editors to introduce more complexity in heat flow scenarios (multiple-layer basement, decoupled thinning, etc.), this kind of approach remains poorly adapted to many areas, notably along hyper-extended margins. The deployment of long-offset seismic has allowed better imaging the deep structure of such margins in many places around the World. These data, together with gravity and magnetic acquisitions, exhibited the structural complexity and heterogeneity that take place along deep and ultra-deep offshore domains, and allowed interpreters to develop advanced concepts to reconstruct the geodynamic history of these areas, from the initial rifting phase to the oceanization. Despite its limitations, standard basin modeling is used to predict the occurrence and the magnitude of thermal events associated with the different extension phases of the margin. For that purpose a workflow has been developed to reproduce geodynamic sketches, integrate and calibrate advanced thermal concepts used in the model. The added value of such an approach to operational petroleum system evaluation studies will be discussed.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Fire and Ice: Application of geodynamic thinking into petroleum system models

Ebbe Hvidegård Hartz[1,2], Sergei Medvedev[2], Daniel W. Schmid[3], Jan Inge Faleide[2], Karthik Iyer[3] & Jon Erik Skeie[1]
[1] AkerBP, Lysaker, Norway
[2] Centre of Earth Evolution and Dynamics, University of Oslo, Norway
[3] Geomodelling Solutions, Zürich, Switzerland

Some estimates (USGS.gov) suggest that the circum-Arctic contains about 1/6 of Earth undiscovered oil, and 1/3 of the undiscovered gas. Exploration for these hydrocarbons is subjected to multiple challenges. Here we discuss geodynamic aspects of these challenges, in particular the influence of major glaciation and active erosion and associated vertical displacements, and how these affect PSM (Petroleum System Modelling). We exemplify this with three regions:

East Greenland displays exhumed giant oilfields, exposed in high mountains cut by deep fjords. It is a long-standing enigma how these marine Mesozoic sediments were uplifted 1 + km above sea-level. We show that in some regions glacial erosion can explain most of the mountainous topography, whereas other regions clearly where uplifted by other mechanisms. The choice of uplift and erosion processes fed into PSM, strongly influence the model outcome, and how these exhumed giants can be used as analogues for other frontiers.

The Barents Shelf represents another frontier area with major PSM enigmas. Most researchers agree that 2-3 km of mostly Cenozoic sediments were eroded from the entire shelf, based on a combination of thermal (e.g., vitrinite reflectance) and load (compaction) arguments. We suggest that classic load argument dominantly reflects ice-loading, rather than sediment loading/erosion, and that the thermal arguments suggest more modest and only sub-regional erosion, coupled with break-up processes/heating along the Continent-Ocean Boundary. Again, the choice of driving processes controls the PSM outcome.

Finally, we show that tilting and pressurizing associated with glacial loading/unloading, and glacial erosion/deposition, greatly influence the seal-strength, pressure and trapped volumes of hydrocarbon giants on the Norwegian continental shelf. For example, the giant Troll field may have lost half its hydrocarbons due to glacial processes, whereas glacial processes may have tilted and pumped hydrocarbons into the giant Sverdrup field.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Integrated 2D seismic interpretation, geometrical forward modelling, 4D analogue modelling and finite element modelling to determine the structure of a giant gasfield in the jungle-covered mountains of Papua New Guinea.

Kevin Hill[1 & 3], Romain Darnault[2], Ruth Wightman[1] and Patrice Rey[4].
1: Oil Search Ltd., Sydney, Australia. 2: IFPN France. 3: 3D-Geo, Melbourne, Australia
4: Basin Genesis Hub, The University of Sydney, Australia

The Hides anticline in the Papua New Guinea (PNG) fold belt is the core part of the PNG LNG project that commenced production in 2015. The structure of the upper 3 km is relatively well constrained from surface data, wells and poor quality 2D seismic data, but the deep structure has been obscure. Seismic data and gravity modelling suggest an underlying large normal fault in basement. Forward geometrical modelling using Move™ and 4D analogue sandbox modelling under an x-ray tomography scanner have greatly constrained the structural interpretation. Using ductile and/or brittle stratigraphies, we tested deformation under the following conditions: pure compression with variable strain rate, inversion followed by compression, and oblique compression. This modelling confirms the presence of the underlying basement fault and suggests that it was mildly inverted prior to the onset of pure compressional deformation in the sedimentary section. The main detachment level was just above basement, ~8-10 km beneath the surface, but this ramped up at the basement fault creating an array of triangle zone faults through the overlying sedimentary section, making the Hides anticline. The early inversion was critical in initiating a backthrust and hinterland-verging tight fold in the Mesozoic section, including the source, reservoir and seal. Deformation in the thick Miocene carbonates at surface was detached from that in the underlying reservoir along an Upper Cretaceous mudstone horizon that varies strongly in thickness such that the 2-4 km high Mesozoic structure verges NE and the overlying Miocene structure verges SW. Analogue modelling shows that a ductile stratigraphy is required with slow strain rates of ~1-3km/M.Y. Our goal now is to digitally reproduce the analogue models in 2D and then 3D using the 'Underworld' finite element modelling code. We can then add variables such as temperature, rheology and isostasy to further refine our understanding.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

From structural 3D restoration to petroleum system modelling

JL Rudkiewicz[1], JF Lecomte[1], D. Colombo[1], I. Faille[1]
[1]IFP Energies nouvelles, 1 et 4 avenue de Bois-Préau, 92852 Rueil-Malmaison, France [2] : author #2 affiliation

Recent advances in the joint IFPEN-Paradigm 3D restoration tool brings new lights into petroleum system modeling, and especially in the way faults are handled. We will show what parameters are derived from faults from 3D restoration and how they can be used in petroleum system modeling.

Sequential 3D restoration generalizes the classical vertical only backstripping as it allows for 3D movement on faults. Faults, as discrete 3D surfaces, separate the 3D rock volume into different fault blocks. Faults thus have a great variety of patterns and hierarchy (faults might be major faults, branching faults, crossing faults ..). For restoration, fault throw for all faults or only for a sub set of faults is usually cancelled on a given stratigraphic horizon. Through geological time, sequential restoration thus delivers real throw distances, as well as flow parameters like SGR.

Moreover, as restoration delivers strain information, the dilatancy of rocks on both sides of faults become available through time. Extension or compression near faults might be used as proxys to allow or prevent fault flow of fluids in petroleum system computation. Because strain is a tensor, the orientation of maximal strain might serve to decide whether longitudinal flow along the fault surface or transverse flow across the fault surface is favored or prevented.

Finally restoration might also be a tool to select which type of petroleum system model is needed: when major strain is almost vertical, classical models with vertical pillar based grids are giving good enough results. However, when major strain is no longer vertical, it is time to switch to more advanced models that allow for horizontal deformation, like IFPEN's new generation.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Towards a Coupled Restoration/Forward Geomechanical Modelling Workflow for Basin Evolution Prediction

Dr. A.J.L. Crook[1], J. Obradors-Prats[1], Dr. D. Somer[2], Prof. D. Peric[2]
[1] : Three Cliffs Geomechanical Analysis Ltd, Swansea, UK
[2] : Swansea University, Swansea, UK

Large-scale geomechanical modelling (1 to 10s km scale) is a key component for assessment of the past, current and future stress/pore pressure state in a range of energy and safety critical applications. Despite the increased interest and application of large-scale geomechanical modelling, there is huge potential to improve the accuracy of basin-scale modelling by incorporation of more realistic representation of the first-order physical processes within restoration and forward geomechanical models. Coupling these models effectively is also challenge, however, due to the large differences in the underlying assumption of the formulations.

Ongoing research of a combined industrial/academic research programme to develop coupled geomechanical/flow/thermal modelling framework for simulation of field-scale and basin-scale evolution over geological time frames will be presented. Particular focus will be given to:

1. Inverse analysis of the past deformation, a pre-requisite for geomechanical forward modelling.
2. Constitutive models with combined mechanical and non-mechanical (chemically driven) evolution.
3. Incorporation of the influence of non-mechanical compaction and overpressure into the restoration model.
4. Methodologies and workflows for iterative coupling restoration and forward prediction models.

The concepts and ideas will be illustrated by reference to both field and experimental observations and also by a series of synthetic benchmarks developed specifically to investigate the accuracy and benefits of workflows for coupled restoration/forward modelling.

Petroleum Systems Modeling Workshop

Challenges of structurally complex basins

Rueil-Malmaison, France - 15-16 June 2017

Coupling Petroleum System and Geomechanics at Basin Scale

Tristan Cornu[1], Marie-Christine Cacas-Stenz[2]
[1] : Total EP R&D
[2] : IFPen

Compressional (or even extensional) settings in complex structural domains are still a challenge in basin modeling (BM) simulation. In particular, the impact of the regional stresses is very poorly understood, and its impact on compaction or fluid flow seldomly described. One way of better integrating the sensibility of petroleum system to stress history goes through coupling of geomechanical and BM approaches. Still, as proven recently with all the developments in coupling reservoir simulations to geomechanics, the choice of coupling two different codes is never an easy target, and usually raises many issues with the numerical compatibility (i.e. meshes, convergence). In the case of basin modeling simulation, an additional difficulty appears with the evolving geometry.

One of the main issues when dealing with complex structural set-up is the capacity to model properly the flow along and across the fault, in agreement with a geological scenario for fault activity. Using the kinematic of the fault coupled to fault permeability evaluation with shale gouge ratio or other methods from the literature, the fault is properly modeled in terms of activity and plumbing impact.

The use of geomechanics in petroleum system modeling has a major impact on porosity and seal integrity evaluation. The computation of the porosity is quite central in the problematic. Traditionally, BM never takes into account any lateral effect in the evaluation of the porosity, nor pressure evolution. Dedicated works were carried out to propose a new constitutive law which takes into account the specific needs of basin model. Finally, the trap integrity is usually confined to very basic tests, with a simple comparison between the pressure and the lithostatic stress. When coupled to geomechanics, the possibility to properly describe the mechanical behavior of the deposited sediments becomes much more descriptive and the possibility to introduce various ways of failure increases as well.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Fully coupled poro-mechanical basin models for pressure and effective stress prediction, with application to a mini-basin in voluminous salt

Peter Lovely[1], Marek Kacewicz[1], Tony Crook[2], Joshua Obradors[2]
[1] : Chevron Energy Technology Company, Houston, TX, USA
[2] : Three Cliffs Geomechanical Analysis Ltd, Swansea, UK

The ability to predict pore pressure and effective stress has implications for many facets of the hydrocarbon industry, from exploration (e.g. reservoir and seal quality, seismic imaging) to drilling and production (e.g. drilling hazards, subsurface integrity, reservoir performance). State-of-the-art modeling approaches for modeling pore pressure and effective stress typically either focus on the present state, omitting geologic history, or simplify rock deformation to vertical shear, in which case only the vertical component of effective stress is considered, and faults and other non-vertical deformation, which commonly occurs in the vicinity of salt, are not represented. Because rheology is temperature dependent, stress and displacement are three-dimensional, and deposition, fluid escape, and pore pressure are time-dependent, robust modeling requires fully coupled thermal-poro-mechanical methods that account for evolution of the system through geologic time.

We present a model that represents the geologic evolution of a mini-basin in voluminous salt, analogous to many structures in the Gulf of Mexico. The 2D model, which could be extended to 3D, accounts for deposition and non-vertical deformation (including compaction and salt flow), coupled to fluid seepage and the thermal field. The coupled analysis is performed using the ParaGeo software from Three Cliffs Geomechanical Analysis, Ltd. The model geometry and rock properties (poro-elasticity, cap plasticity, porosity-permeability relationships, etc.), are calibrated using laboratory rock mechanics studies and subsurface data, such as well logs and seismic interpretation. We discuss the calibration workflow, as well as challenges and limitations of calibrating a highly nonlinear model, which is based on physical first-principles, and we explore the implications of the geomechanical basin model, which accommodates non-vertical deformation and stress.

Petroleum Systems Modeling Workshop

Challenges of structurally complex basins

Rueil-Malmaison, France - 15-16 June 2017

Geophysical Basin Modelling: Methodology and Application in Complex Geological Settings

Giuseppe De Prisco[1], Yaping Zhu[1] , Marin Laomana[1] , Teresa Szydlik[1]
[1] : Statoil Gulf Service, Houston

The quality of a seismic imaging is strongly related to the ability to obtain an accurate velocity model. This task is very challenging in complex areas such as subsalt, where conventional modeling methods relaying solely on the information contained by the seismic data and often struggle to provide good quality velocity models.

Present day seismic velocities are depending on the basin evolution or "geo-history", so a quantification of geological information estimated using a basin model, has an obvious potential in assisting seismic velocity model building. However, different geological hypothesis can be formulated to build the model of a basin itself, especially in geological settings where rapid depositional rates and complex salt dynamics characterize the region of interest. For instance, the evolution of secondary basins can be challenged by different interpretations and hypothesis: a mini basin that was initially filled by salt before space was made to accommodate new sediment deposition has different geo history than the same mini basin that initially was filled by clay. These different geo scenarios are going to give different time evolution of temperature and effective stress in input to the rock model, that is going to produce different velocity models.

The different geological scenarios are modeled by different basin models with the constrain that modelled temperature and pore pressure at well locations are matching present day measurements. The depositional attributes of the rock model are also calibrated at well locations to match the velocity logs at present day. However, the different basin models are giving different velocity at locations different than the wells because of the different geo histories. This in turn will result in different seismic images for each model that are fundamentally quantifying a geological uncertainty within the basin model.

This work is trying to underline these aspects, using the combination of a basin model and a rock model (Geophysical Basin Model). A prospect in the deep water Gulf of Mexico is used in this study.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Integrating basin modeling and rock physics to predict reservoir rock lithofacies and chemical diagenesis effects on overpressure

Wisam AlKawai[1], Allegra Hosford Scheirer[1], Tapan Mukerji[2], Stephan A. Graham[1]
[1] : Stanford University, Department of Geological Sciences
[2] : Stanford University, Departments of Energy Resources Engineering and Geophysics

Basin and petroleum system modeling (BPSM) is a powerful tool for addressing the evolution of rocks and the fluids generated by them in sedimentary basins. BPSM becomes even more powerful when integrated with other disciplines. In this talk we combine BPSM, rock physics, and quantitative seismic interpretation (QSI) to improve predictions of 1) the spatial distribution of lithofacies in reservoir rock intervals and 2) overpressure zones associated with smectite-to-illite (clay) diagenesis. Our results are demonstrated in the Thunder Horse mini-basin of the Gulf of Mexico. The major challenges of this case study are the role of salt and rapid sedimentation. To start, a 2D basin model crossing the mini-basin is structurally restored, with particular consideration of salt emplacement. Temperature and pressure histories are determined with basin modeling. These then feed into rock physics templates, which provide pseudo logs of elastic properties for QSI. From this workflow, we eventually obtain the most likely lithofacies at each point in the grid and in each reservoir rock interval. A powerful result is thus the identification of stacked pay in the study area. The importance of integrating chemical kinetics of smectite-to-illite conversion into pore pressure prediction is well known. Current methodologies consider the smectite-to-illite conversion kinetics based on a simple thermal history model in which geothermal gradients and sedimentary burial rates are assumed to be constant. In this study, we demonstrate that a time-dependent solution thermal history must be considered in areas affected by salt emplacement and rapid sedimentation. The workflow for both parts of the study is demonstrated in the case of limited well control, which will improve exploration and production.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Contribution of carbonate diagenesis to the thermicity, compaction and paleo-stress appraisal in basin analysis – case of the Paris Basin

Gasparrini, M.[1], Mangenot, X.[1,2], David, M.E[3,1], Bonifacie, M.[2], Gerdes, A.[4], Rouchon, V.[1], Lacombe, O.[2], Beaudoin, N.[5], Youssef, S.[1]

[1] : IFP Energies nouvelles, Rueil-Malmaison, France
[2] : IPGP, Paris, France
[3] : UPMC, Paris, France
[4] : Goethe University, Frankfurt, Germany
[5] : University of Glasgow, UK

Diagenesis may strongly modify primary petrophysical properties of carbonate rocks via processes of cementation, replacement, fracture healing etc. One of the challenges of conducting diagenesis characterization studies is to quantify thermal conditions and ages of these modifications to assess their occurrence in time and space (paragenesis). This has an impact on the confidence of subsequent basin models, whose accuracy also critically affects the understanding of basin evolution and the simulations of hydrocarbon generation and fluids (water, oil, gas) migration.
Chemical compaction is a diagenetic process affecting sedimentary series during burial that may result in dissolution of important rock volumes and porosity reduction along Bedding Parallel Stylolites (BPS). The factors controlling the BPS development and the total thickness of carbonate dissolved are still not fully understood and are at present not taken into account in thermal or flow simulations at basin scale.
New promising methods are developing to face these problematics. In particular, the carbonate clumped isotopes thermometer (Δ_{47}) allows temperature estimations that overcome common carbonate petrographic limitations and the U-Pb analyses by LA-ICP-MS allows to date carbonate crystallisation directly on thin sections by requiring low U contents. On the other hand, more quantitative approaches to evaluate chemical compaction and paleo-stress can be applied and include image analysis and morphometry of the stylolite traces.
A reservoir unit of the Paris Basin from sub-surface cores (Bathonian Sup. –Callovian Inf.; *Calcaire de Comblanchien*) was chosen to apply these techniques. The aim was to quantify both absolute temperature and timing of different cementation phases (from carbonate thermo-chronology) and to estimate chemical compaction and maximum vertical paleo-stress experienced by the host carbonates (from BPS study). These constraints will contribute to a future better appraisal of thermicity, compaction and paleo-stress in the process of basin analysis and modelling.

Basin Modeling in 2D Complex Structural Areas: Issues and Existing Solutions for the Complex Geological Scenarii

Romain Darnault[1], *Thomas Crabie*[1], *Renaud Divies*[1], *Jean-François Lecomte*[1], *Marie Callies*[2]

1 : IFP Energies Nouvelles – 1-4 avenue de Bois Préaut, 92852 Rueil-Malmaison, France
2 : Beicip Franlab – 232 avenue Napoléon Bonaparte, 92500 Rueil-Malmaison, France

A "complex" structural area is commonly known to be a faulted and folded system, sometimes also affected by ductile movements (anhydrites, shales) with displacements of the structural blocks. In basin modeling these "complex" systems are translated by calculation made with unstructured mesh for simulations. Exploration in such areas is now usual and the "classical" workflows used in basin modeling have been adapted through time to handle petroleum system modeling in complex structural settings. Combining structural restoration and basin modeling packages, the classical workflow require a three step process: building the present day model from both geological and geophysical data, performing the restoration with appropriate software and then exporting the paleo-models collection to the basin modeling software in which simulators are able to model fluid migration through faults and rocks.

With the increase of the geological complexity, some practical limitations have emerged, which drastically impact the operational use of the software. Moreover, each step of the workflow should be connected with the others, but the tools used for each step are not always elaborate in this way.

We here show what are the limitations and what solutions can be used to overcome them. We demonstrate how these solutions aim at producing easily and rapidly consistent meshed geological scenarii in the aim to generate basin models with simulators able to manage an unstructured mesh. We focus on the restoration part, where the improve of the ergonomy, with the development of new algorithms for the manipulation of a cross section, the use of a scenario scheduler able to manage the restoration as well as the layering and several handy and efficient engines of deformation are the key elements to reach the targets.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Workflow to model non uniaxial effects in uniaxial basin models at early stage exploration, while keeping the model as simple as possible.

Toby Harrold[1], Sara Martinez[1], André Vayssaire[1], Pascal Rouillé[1] , Oscar Fernandez[1], Jean Joseph D'Hooghvorst[2]
1: Repsol Exploracion SA, Mendez Alvaro 44, Madrid 28045 España.
2: Facultat de Geologia, Universitat de Barcelona, Barcelona 08028

Exploration prospects are increasingly being evaluated into areas of more complex tectonic stress environments with very poor or non-existent offset well data. These environments present challenges to conventional techniques to assess our prospects in particular our petroleum systems, pore pressure and seal capacity assessment which are traditionally designed for vertical stress dominated environments. While it is possible to build more complicated models... time, data and resource restrictions often preclude a more complete analysis. This talk presents a simple workflow to deviations from uniaxial conditions via manipulation of the vertical stress to simulate the increase or decrease in horizontal stresses. While this is not a perfect solution, it represents an attempt the complexity which we know exists and allows us to integrate our results with other techniques.
Two case studies are presented, one where horizontal stress increase of a fold and thrust belt system has been represented in the analysis and a second where horizontal (and mean) stress reduction is predicted as a result of salt tectonics. The workflow allowed us to compare and integrate our analysis with offset well, seismic and geomechanical analysis using the same set of assumptions on a timescale consistent with the exploration process.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

Secondary Hydrocarbon Migration in Complex Multi-Carrier Settings - Some Practical Insights

Sascha Doering[1], Stefano Castellani[1], Luca Baruffini[1]
[1]Eni S.p.A. Upstream & Technical Services

Petroleum systems modelling in multiple carrier settings is a challenging exercise, which requires the simplification of the geological system in a fashion that still allows for a reasonable representation of the key geological aspects involved. In such settings, the accurate definition of traps is of key importance as these define areas of possible vertical leakage. However, in many typical datasets used for petroleum systems modelling studies, an accurate trap definition is not given and thus migration modelling results can have a limited meaning for the prediction of hydrocarbon charge of prospects.

Petroleum systems modelling studies in relatively well-explored areas allow to understand the limitations of migration models and also help to developing workflows for less-explored areas using standard tools. We examined such cases in West and North Africa making use of detailed hydrocarbon show databases, which were utilized for model validation. Trap types in these models are stratigraphic, structural or combined, resulting in a high level of complexity. The reservoir depositional environments in these studies vary from deep water turbidite systems to shallow marginal marine settings and shallow marine settings.

We observed that depending on structural style, reservoir fairways can have a different significance for secondary migration. Our models show, that regional facies patterns have less meaning in strongly structured settings dominated by salt tectonics or rotated fault blocks whereas these have a stronger meaning in less structured petroleum systems.

There is often much focus on scenario or probabilistic approaches concerning maturation and expulsion, whereas defining different scenarios concerning migration pathways is less often done due to the lack of data or due to time constraints. We believe that in multiple carrier settings, a significant part of our time should be spend on this activity applying higher automatized workflows which help to achieve this in an efficient way.

Petroleum Systems Modeling Workshop
Challenges of structurally complex basins
Rueil-Malmaison, France - 15-16 June 2017

3-D Numerical Stratigraphic Forward Modeling of Rifts: Characterizing Reservoir Presence Risk

Ashley D. Harris[1], Peter J. Lovely[1], Sarah E. Baumgardner[1], Kaveh Ghayour[1], Todd Engelder[1], Tao Sun[1], Robert P. Lyons[2], and Didier Granjeon[3]

[1]Chevron Energy Technology Company, Houston, TX, U.S.A.;
[2]Chevron Frontier Exploration and Appraisal Business Unit, Houston, TX, U.S.A;
[3]Department of Geology-Geophysics-Geochemistry, IFP Energies Nouvelles, Rueil-Malmaison, France

Continental rifts are of great interest and relevance to scientists and the general public because they contain numerous depositional environments at relatively compressed spatiotemporal scales, continuous climate records, and hydrocarbon resources. The interaction of climate, sediment routing, and tectonism controls the distribution and continuity of the depositional environments, but these relationships are nonlinear and complex. Conceptual stratigraphic models provide useful insight into facies distribution but are typically qualitative and may not capture the full range of geologically plausible scenarios generated by these interactions. Here, we demonstrate that a deterministic, nonlinear, diffusion-based forward stratigraphic model can approximate key tectonostratigraphic processes interpreted from continental rift systems and can be applied to exploration risk assessment. This sediment transport model acts upon a simple elastic tectonic model that approximates appropriate distributions of subsidence and uplift associated with a schematic fault architecture typical of early stage continental rifting. The model is subjected to a series of base-level, sediment supply, and water discharge scenarios, and the results of the ensemble of model realizations are synthesized into a sand presence probability map. These maps can then be used to high-grade specific areas and/or timeframes for further study. This simple sensitivity analysis can be conducted by academic and industry groups to better characterize facies distribution and quantify uncertainties associated with continental rifts.

Innovating for energy

IFP Energies nouvelles
1 et 4, avenue de Bois-Préau
92852 Rueil-Malmaison Cedex - France
Tel. : +33 1 47 52 60 00

Lyon site
IFPEN-Lyon
Rond-point de l'échangeur de Solaize
BP 3 - 69360 Solaize - France
Tel. : +33 4 37 70 20 00

www.ifpenergiesnouvelles.com

@IFPENinnovation